(NASA-CR-173403) SHUTTLE INTERACTION STUDY EXTENSION Midterm Review (Rockwell International Corp.) 160 p HC A08/MF A01 CSCL 14B
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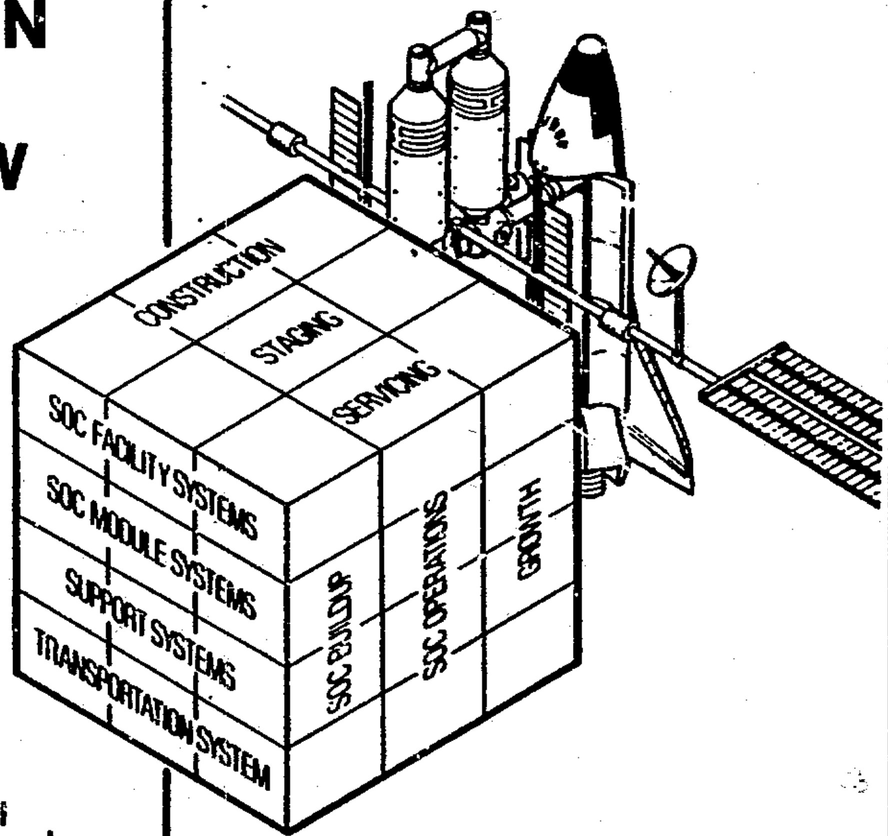
SPACE OPERATIONS CENTER

SHUTTLE INTERACTION STUDY EXTENSION

MID-TERM REVIEW

NAS9-16153



Space Operations/Integration & Satellite Systems Division

Rockwell International

15 OCT 1981

STUDY OBJECTIVE

"ANALYZE, IN A PRELIMINARY FASHION, THE IMPLICATION OF USING THE SHUTTLE WITH THE SOC, INCLUDING CONSTRAINTS THAT THE SHUTTLE WILL PLACE UPON THE SOC DESIGN. IDENTIFY ALL THE CONSIDERATIONS INVOLVED IN THE USE OF THE SHUTTLE AS A PART OF THE SOC CONCEPT."

- IMPLICATIONS TO THE SOC
- IMPLICATIONS TO THE SHUTTLE
- IMPLICATIONS TO AN OTV/MOTV

STUDY TASKS

TASK	ISSUES
1.0 ORBITAL ALTITUDE	• AT WHAT ALTITUDE SHOULD THE SOC OPÉRATE WHILE BEING COMPATIBLE WITH THE SHUTTLE CAPABILITIES?
2.0 BERTHING AND/OR DOCKING	• IS A STANDARD BERTHING/DOCKING INTERFACE FEASIBLE? • CAN THE ORBITER DOCK TO THE SOC? • CAN THE ORBITER BERTH TO THE SOC USING THE RMS?
3.0 SOC ASSEMBLY	• WHAT EQUIPMENT AND OPERATIONS ARE REQUIRED FOR THE SHUTTLE TO ASSEMBLE THE SOC? • WHAT ARE THE IMPLICATIONS TO THE SOC ELEMENTS?
4.0 SOC RESUPPLY AND FUEL TRANSFER	• WHAT ARE THE IMPLICATIONS OF SOC RESUPPLY VIA THE LOGISTICS MODULE AND THE SHUTTLE? • WHAT ARE THE IMPLICATIONS OF TRANSFERRING PROPELLANTS FROM THE SHUTTLE TO THE SOC? • DEVELOP A SHUTTLE LOGISTICS MODEL
5.0 FLIGHT SUPPORT FACILITY	• WHAT ARE THE IMPLICATIONS TO THE SOC TO PROVIDE SPACECRAFT SERVICING? • WHAT ARE THE IMPLICATIONS TO THE SHUTTLE TO PROVIDE SPACECRAFT SERVICING? • WHAT ARE THE SPACE-BASED VEHICLE REQUIREMENTS?

EXECUTIVE SUMMARY

FLEET UTILIZATION ANALYSIS

SHUTTLE SYSTEM PROPELLANT SCAVENGING

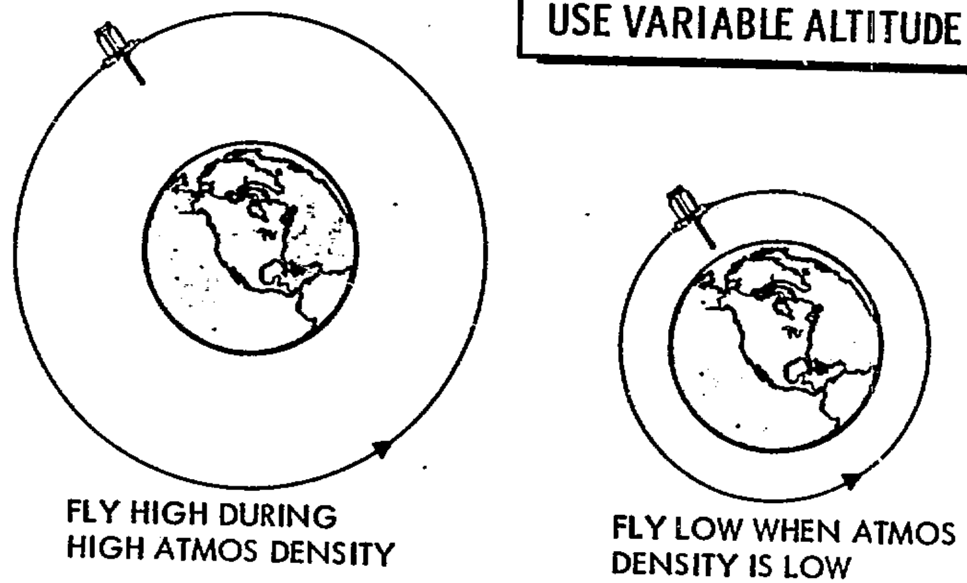
SOC ASSEMBLY OPERATIONS

FLIGHT SUPPORT FACILITY

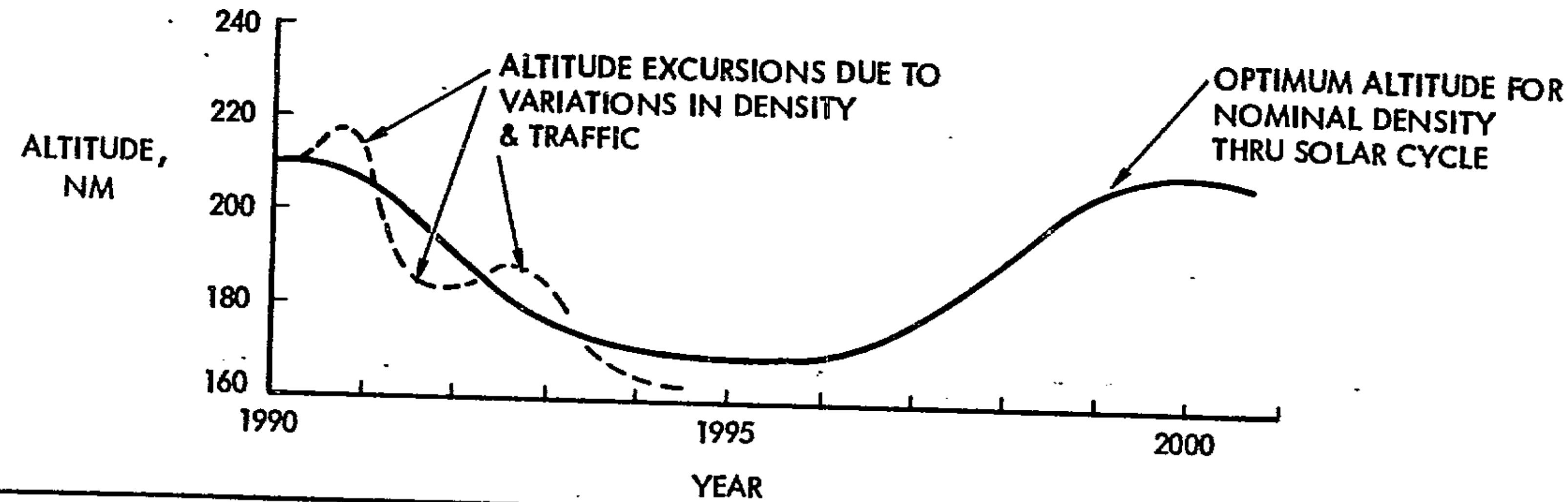
CONCLUSIONS & PLANS

ORBITAL ALTITUDE

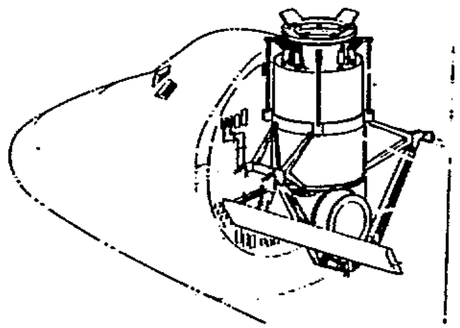
USE VARIABLE ALTITUDE STRATEGY ✓



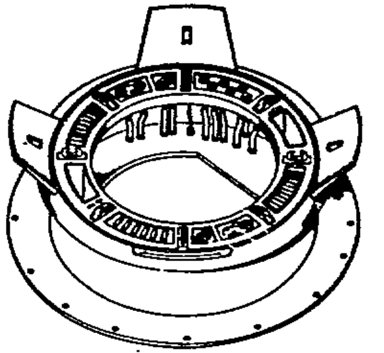
- CAPITALIZES ON GREATER SHUTTLE P/L'S AT LOW ALTITUDES
- COMBINES ORBITAL SAFETY WITH EFFICIENCY
- SAVES UP TO 15% LOGISTICS OVER CONSTANT ALTITUDE STRATEGY



BERTHING AND/OR DOCKING

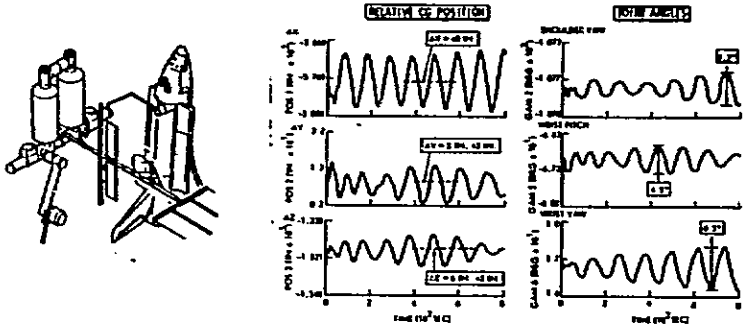


DOCKING MODULE CONCEPT

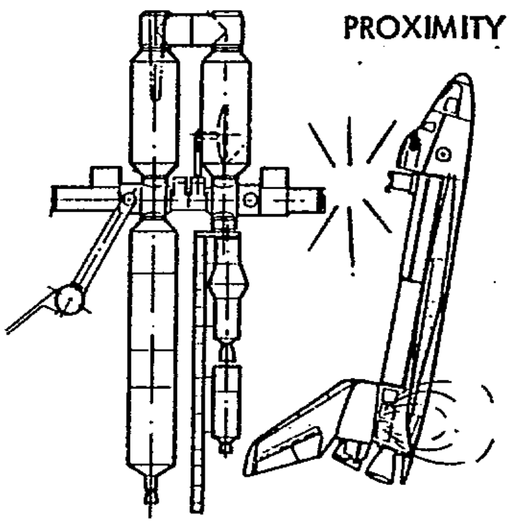


COMMON INTERFACE DESIGN IS POSSIBLE

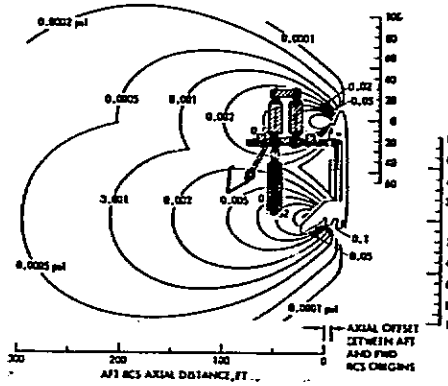
RMS BERTHING IS FEASIBLE BUT REQUIRES SOFTWARE MODS



PROXIMITY OPERATIONS



- CLOSURE PATH EFFECTS
- RUNAWAY JET
- ABORTS FROM RUNAWAY JET ARE POSSIBLE
- SOC DESIGN FOR THRUST WHILE DOCKED

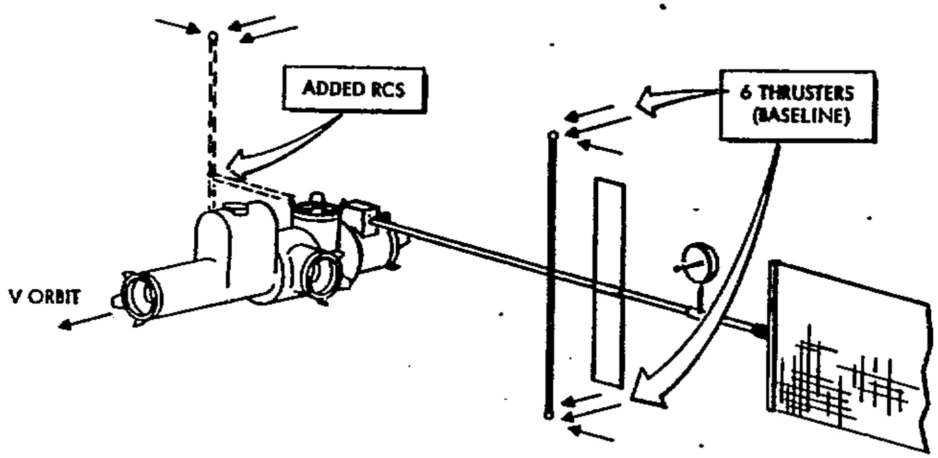


PLUME IMPINGEMENT

- DESIGN FOR "HI Z" ABORT MODE
- LONG TERM CONTAMINATION NEEDS STUDY

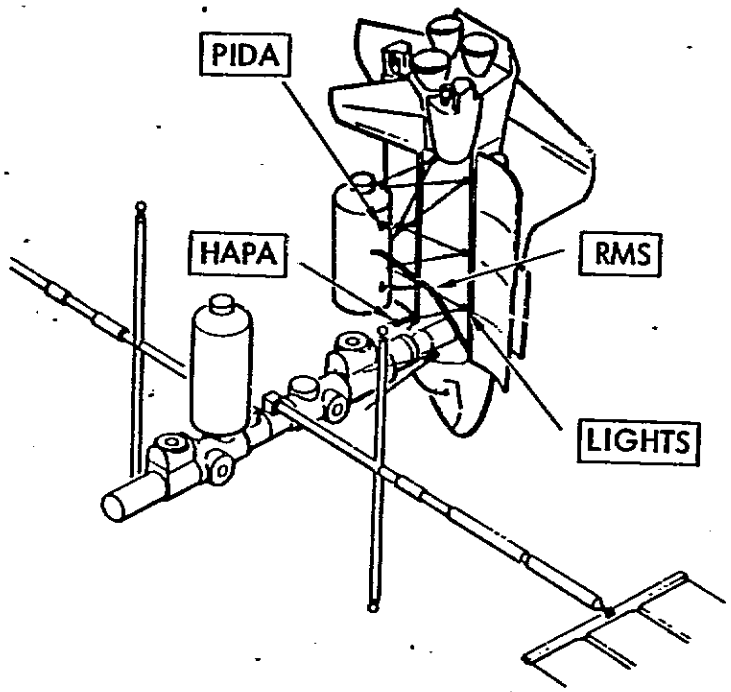
SOC ASSEMBLY

- ASYMMETRIC CONFIGURATION PROBLEMS



- RCS SUPPLEMENT REQUIRED FOR SOC BUILDUP

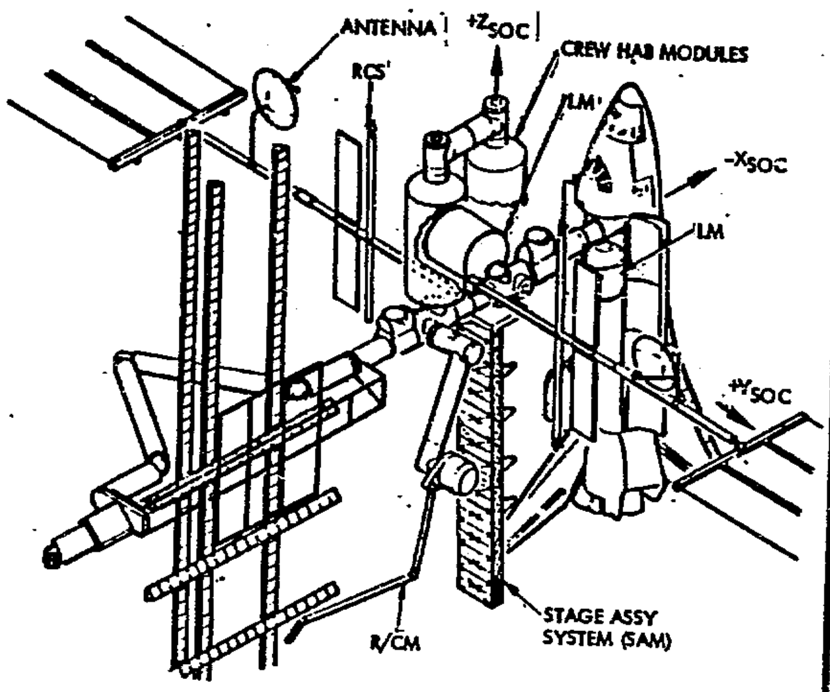
- SOC CAN BE ASSEMBLED WITH ORBITER PROVISIONS IN DEVELOPMENT OR PLANNED



PLUS SUPPLEMENTAL LIGHTS & ALIGNMENT AIDS

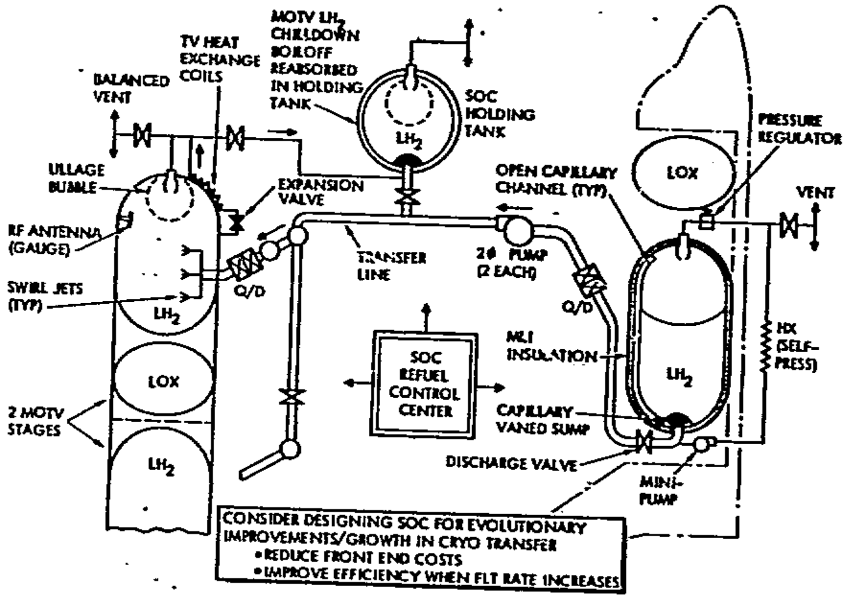
SOC RESUPPLY AND FUEL TRANSFER

LOGISTICS OPERATION



- LOGISTIC MODULE EXCHANGE
- FLIGHT SUPPORT FACILITY LOGISTICS
- CONSTRUCTION LOGISTICS

PROPELLANT TRANSFER



- ZERO "G" TRANSFER IS FEASIBLE
- PROPELLANT STORAGE HIGHLY DESIRABLE

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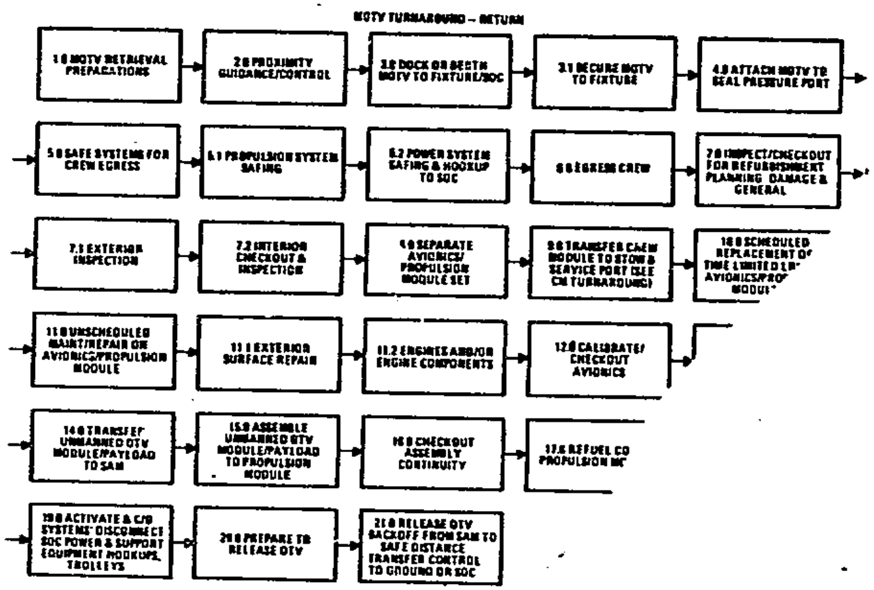
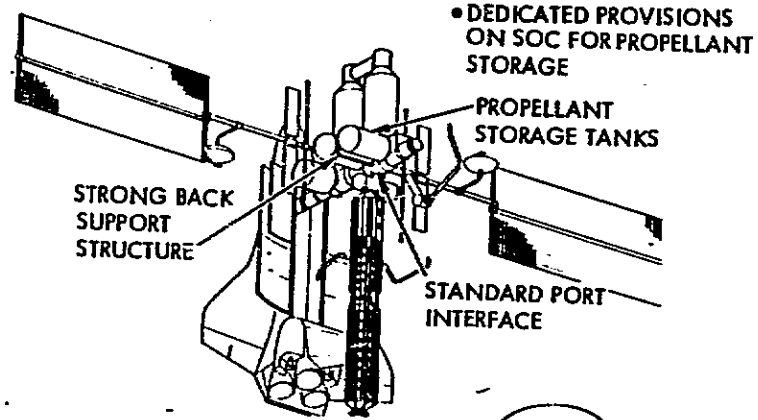
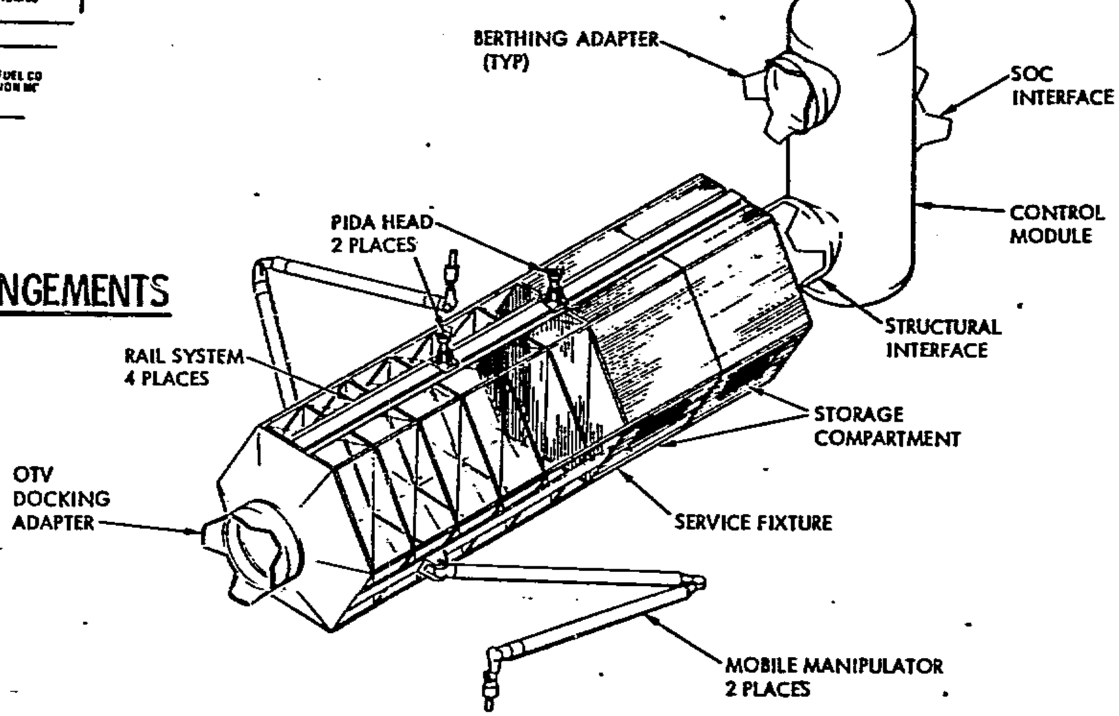
FLIGHT SUPPORT FACILITY

FUNCTIONAL REQUIREMENTS





FACILITY ARRANGEMENTS



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STUDY EXTENSION TASKS

TASK 1.0 SHUTTLE FLEET UTILIZATION & PROGRAMMATICS

OBJECTIVE: DETERMINE SHUTTLE FLEET UTILIZATION REQUIREMENTS & RELATED PROGRAMMATICS DATA FOR SOC/SHUTTLE OPERATIONS IN LEO.

TASK 2.0 SOC ASSEMBLY OPERATIONS

OBJECTIVE: TO CONFIRM THE CAPABILITY OF THE RMS TO ASSEMBLE THE SOC, & TO DETERMINE THE ASSEMBLY OPERATIONAL IMPLICATIONS & THE IMPLICATIONS TO THE SOC MODULES

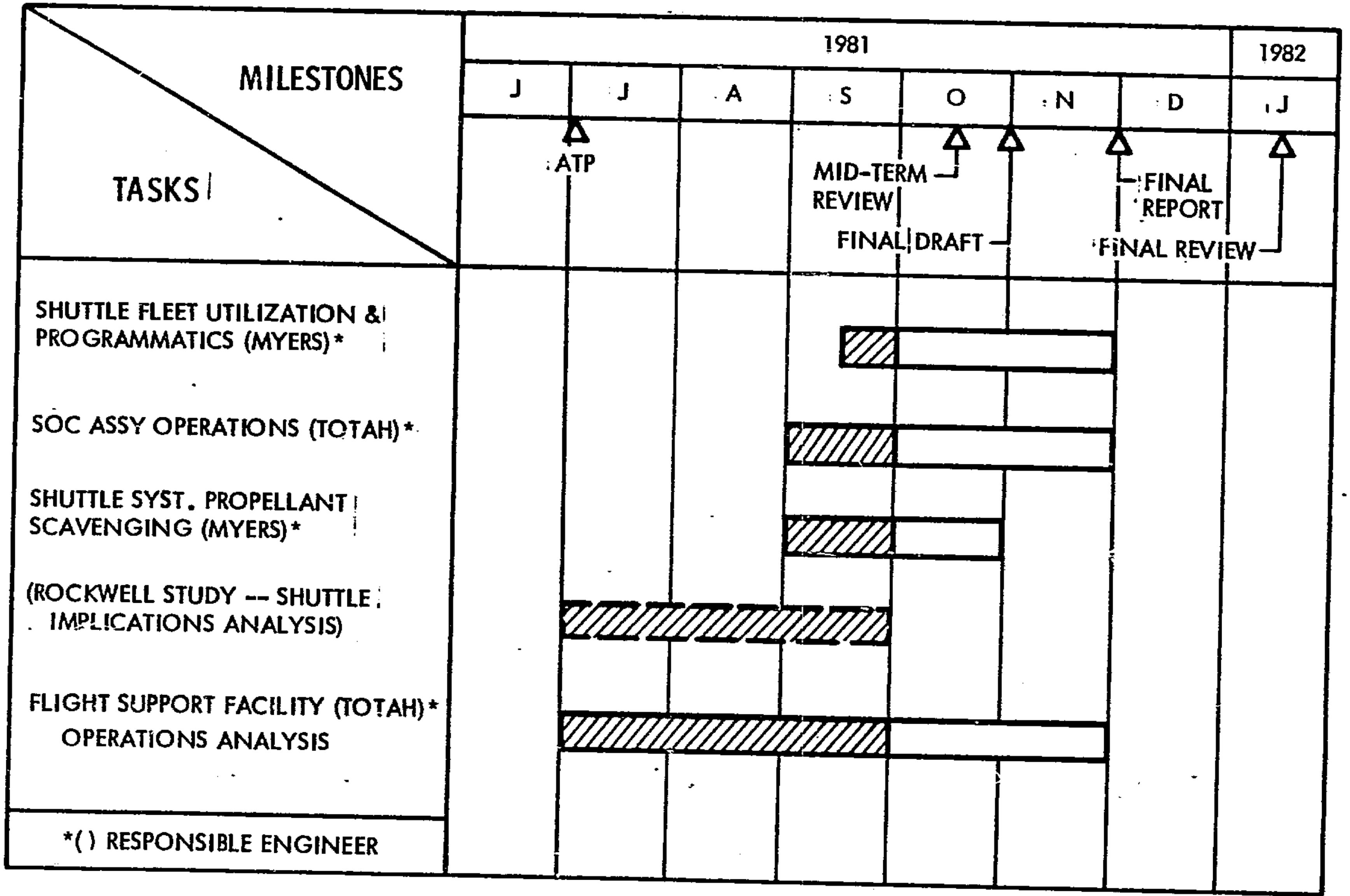
TASK 3.0 SHUTTLE SYSTEM PROPELLANT SCAVENGING

OBJECTIVE: DETERMINE PRINCIPAL FUNCTIONAL IMPACTS ON THE SOC DUE TO PROPELLANT SCAVENGING

× TASK 4.0 FLIGHT SUPPORT FACILITY

OBJECTIVE: TO COMPARE THE SERVICING/CHECKOUT LOGIC & COSTS ASSOCIATED WITH PERFORMING FLIGHT SUPPORT SERVICES ON FREE-FLYING SATELLITES & OTV'S AT THE SOC, ON THE GROUND & FROM THE ORBITER

TASKS SCHEDULE



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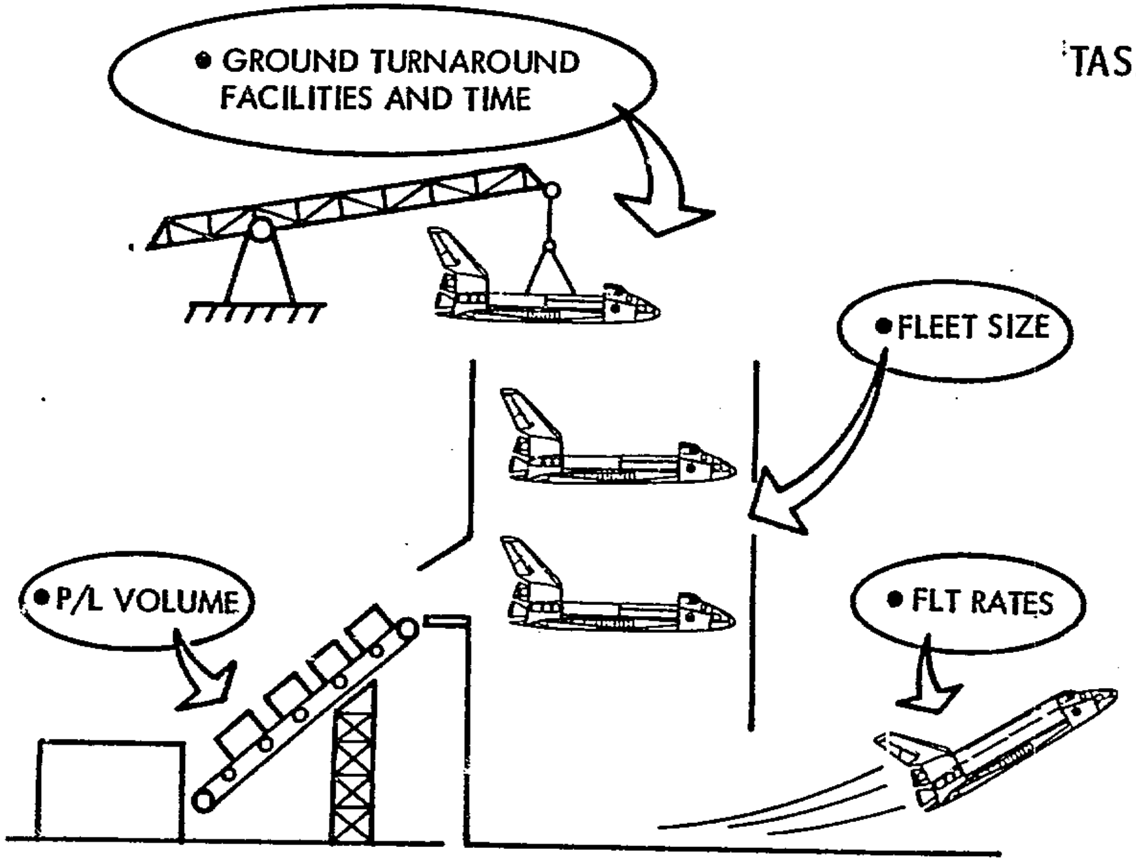
SHUTTLE FLEET UTILIZATION & PROGRAMMATICS

This task will determine the key interrelationships among the main STS utilization variables, with particular emphasis on the differences between SOC and "non-SOC" scenarios. We will be looking at the interacting effects of cargo density, OTV performance models, and Shuttle logistics performance for their effects on fleet utilization and fleet size requirements. In particular, we will examine the potential benefits within the SOC scenario of increasing Shuttle load factors by adding high-density propellants to low-density cargo manifests to always fly the orbiter near its 65K lb payload capacity.

The further fleet utilization benefits of scavenging ET residual propellants will also be investigated. This technique is particularly suited to the SOC scenario where propellant storage capability in space could easily be provided as part of the SOC flight support activity.

It is also planned to investigate the potential ground turnaround benefits which can be attained with an orbiter dedicated to SOC resupply missions.

SHUTTLE FLEET UTILIZATION AND PROGRAMMATICS



TASK SCOPE AND APPROACH DEFINED

- TRAFFIC ANALYSIS
- MANIFEST DEFINITIONS
- TRADES:

  SOC VS NO SOC
  DEDICATED ORBITER
  SOC PROPELLANT STORAGE
  P/L TOP-OFF TANK SIZES
  ET PROPELLANT RECOVERY

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SUMMARY

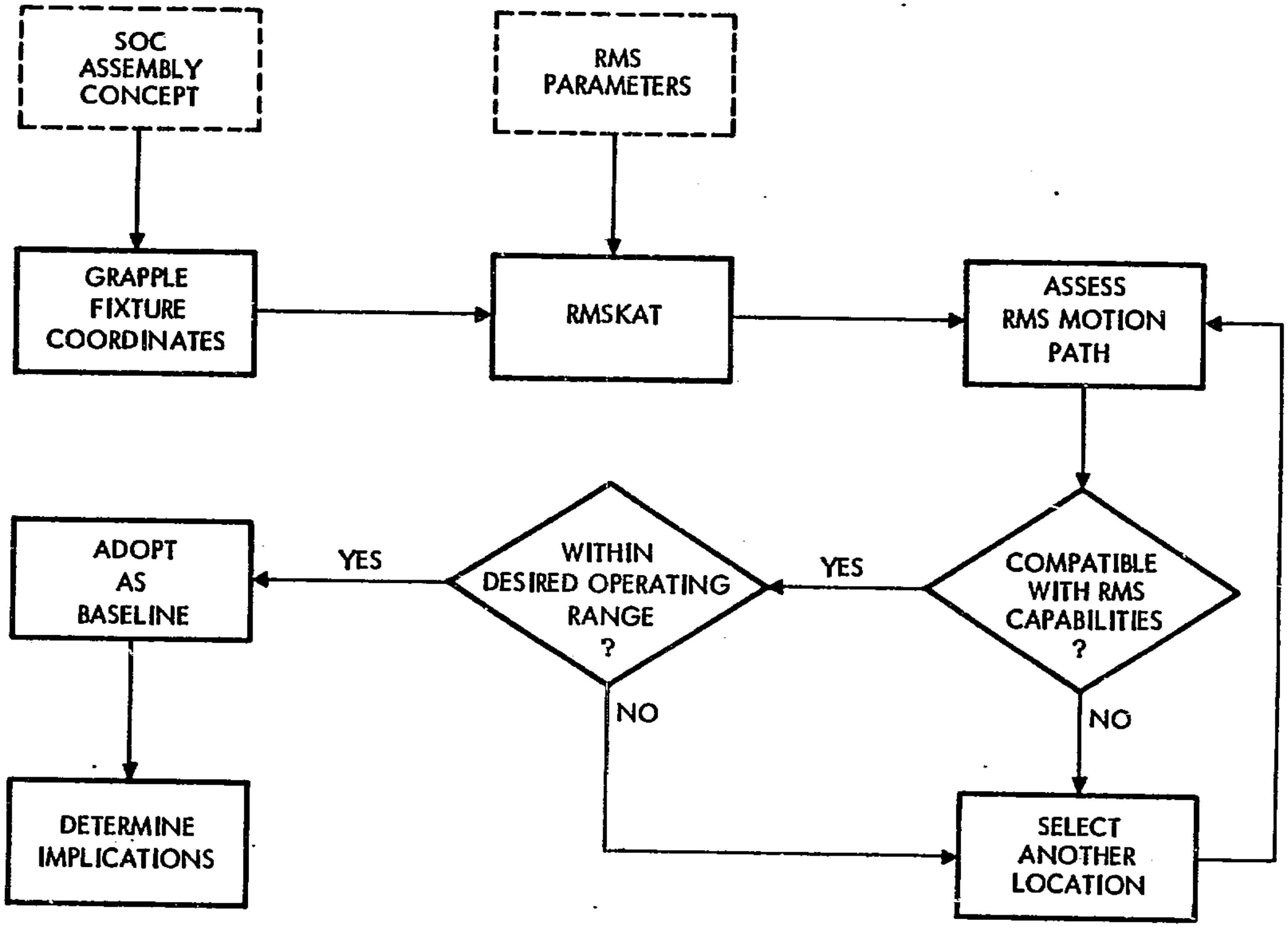
GOALS:

- DEVELOP AN UNDERSTANDING OF THE GROUND TURNAROUND PROCESS & POTENTIAL SOC RELATED INTERACTIONS
- DETERMINE THE SIGNIFICANCE &/OR NEED FOR DEDICATED ORBITER(S)
- SHOW FLEET IMPACTS FROM NON-SOC SCENARIO
- DETERMINE PROPELLANT TANK SIZES MATCHING TRAFFIC PREDICTIONS . . . , AND UNDERSTAND THE INTERACTIONS WITH PAYLOAD DENSITY, ET SCAVENGING AND PAYLOAD TOP OFF

TASK 2—SOC ASSEMBLY OPERATIONS APPROACH

Our approach to the Assembly Operations task is to use a company-developed computer program RMSKAT (Remote Manipulator System Kinematic Analysis Tool). The program assesses the motion path the RMS is expected to follow in assembling each module, and indicates whether it is within the capability and desired operating range of the RMS. The assessment is based on a SOC assembly concept that was generated during our initial effort on the SOC/Shuttle Interaction Study. From that concept, grapple fixtures were located on each module and the initial and final end effector coorcinates were determined for each assembly operation. The coordinates served as the inputs to the RMSKAT computer program.

TASK 2 - SOC ASSEMBLY OPERATIONS APPROACH



REMOTE MANIPULATOR SYSTEM KINEMATIC ANALYSIS TOOL (RMSKAT)

The RMSKAT program is used for the kinematic evaluation of the RMS operational envelopes. It features rigid body simulations only, i.e., without flexible body effects. Besides the typical computer printouts, the program presents a graphic feedback of the kinematic path of the RMS and its grappled payload. Both types of output are illustrated on the next two charts. Incorporation of the SOC graphics is partially complete at this time.

RMSKAT can be operated in any one of two modes, as indicated.

REMOTE MANIPULATOR SYSTEM KINEMATIC ANALYSIS TOOL (RMSKAT)*

- COMPUTER PROGRAM FOR KINEMATIC EVALUATION OF RMS OPERATIONAL ENVELOPES
- RIGID BODY SIMULATIONS ONLY
- GRAPHIC FEED BACK (SOC GRAPHICS MOD IN PROGRESS)
- TWO OPERATING MODES

INPUT

- START & FINAL END EFFECTOR COORDINATES & ORIENTATION IN ORBITER REFERENCE SYSTEM
- RMS JOINT ANGLE SPECIFICATIONS

OUTPUT

- RMS JOINT ANGLE READINGS AT SPECIFIED TIME INTERVALS
- END EFFECTOR COORDINATES & ORIENTATION IN ORBITER REFERENCE SYSTEM

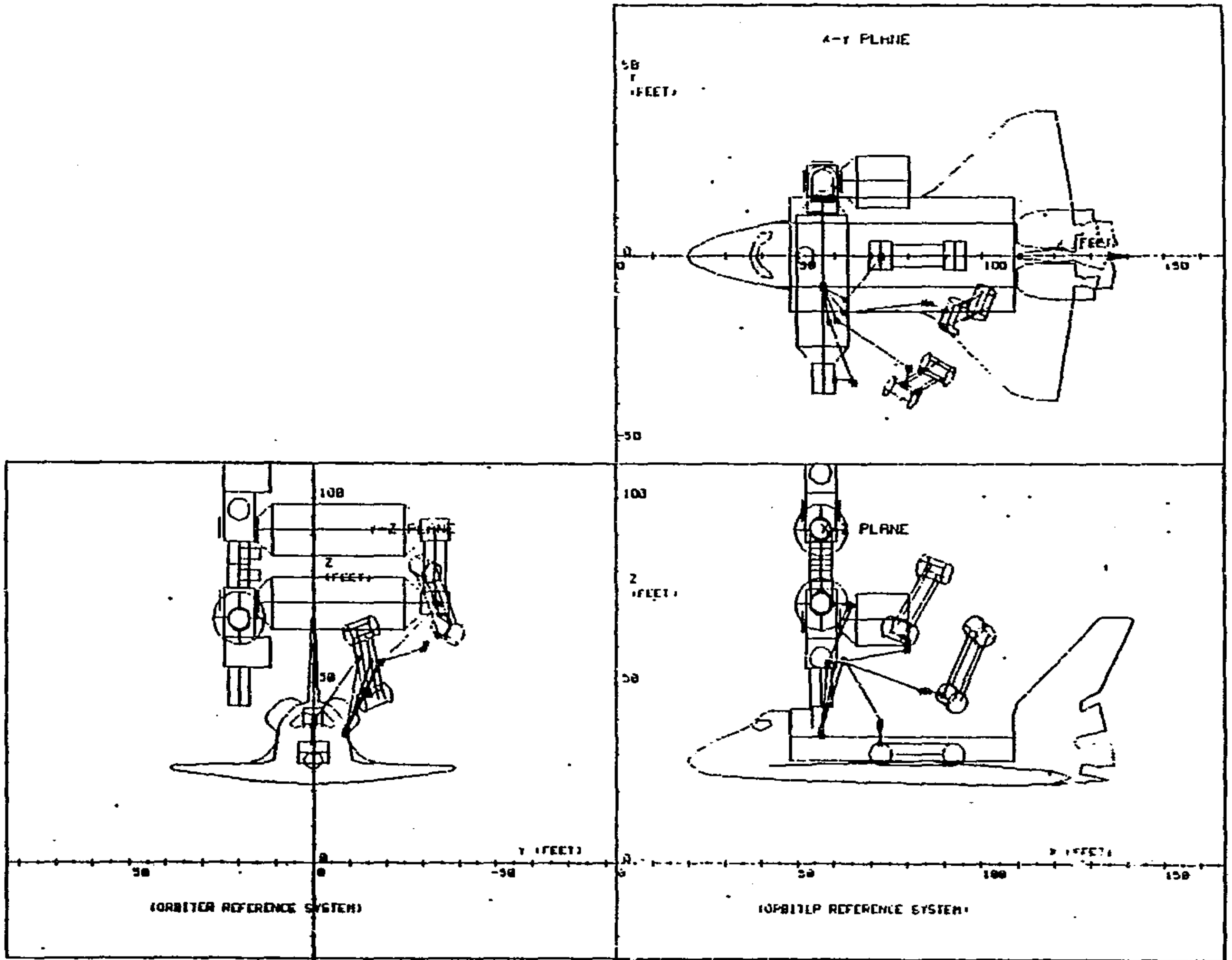
*DEVELOPED WITH DISCRETIONARY FUNDS

SOC TUNNEL ASSEMBLY

This chart illustrates a typical graphic output of RMSKAT. In this particular example, the assembly operation of the SOC tunnel module is featured. It should be noted that the SOC interfaces with the orbiter on an assumed handling and positioning aid (HPA) which places the SOC interface outside the orbiter payload bay envelope. The use of the HPA was found necessary to bring the depicted tunnel assembly operation within the reach limits of the RMS.

Another point of interest for the RMS is the geometric relationship of its wrist segment to its lower-arm segment, as can be clearly seen in the upper sketch. The relationship is an acute angle, and this was one of two points that were found to exceed the wrist pitch joint limits, as indicated on the next chart.

SOC TUNNEL ASSEMBLY



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RMS ANGLES—SOC ASSEMBLY

Assessment of the first set of grapple fixture locations, as determined by the base-lined assembly sequence, resulted in the RMS joint angles indicated on this chart. Grapple fixture locations on two modules, Service Module No. 1 (SM-1) and the tunnel module (TM), were found to exceed the wrist pitch joint limits. The operational limits of each RMS joint are indicated in the heading of each column. Besides the operational limits, certain desired limits exist for the elbow pitch and the wrist yaw joints which state that the wrist pitch joint should be less than ±60° at the time of berthing and, similarly, the elbow joint should be greater than -40°. The circled results exceed these desirements and, consequently, grapple fixtures on the affected modules will be relocated and reassessed until compatible locations are found.

RMS ANGLES -- SOC ASSEMBLY

MODULE	SY (-177.4 TO 177.4)	SP (0.6 TO 142.4)	EP (-0.4 TO -157.6)	WP (-116.4 TO 116.4)	WY (-116.6 TO 116.6)	WR (-442 TO 442)
SM-1 STOWED	-31.54	50.71	-72.86	-11.92	-53.47	-28.52
↓	-46.68	68.02	-82.50	51.77	-61.30	17.48
	-61.82	85.34	-92.14	115.45	-69.13	63.48
SM-1 DEPLOYED	-76.97	102.65	-101.79	179.14	-76.97	109.48
SM-2 STOWED	-32.82	54.09	-78.37	-8.85	-52.40	152.65
SM-2 DEPLOYED	-32.59	76.54	-85.32	-92.01	16.32	-55.85
HM1 STOWED	-30.93	60.48	-82.34	-12.68	-53.97	-29.10
HM1 DEPLOYED	-21.64	78.56	-42.91	-79.48	-61.20	140.00
HM2 = HM1						
LM STOWED	-28.62	53.82	-72.01	-18.26	-55.85	148.57
LM DEPLOYED	-61.31	75.58	-68.93	-28.61	-26.91	169.66
TM STOWED	-28.99	71.21	-133.56	-37.38	-16.96	120.45
↓	0.54	75.00	-97.30	15.80	30.20	56.70
	27.91	78.80	-61.10	69.10	43.30	6.90
TM DEPLOYED	56.36	82.58	-24.99	122.41	56.36	-70.52

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SHUTTLE SYSTEM PROPELLANT SCAVENGING

There is 9500 lb of propellant or more remaining in the ET at the end of boost. This includes flight performance reserves, trapped residuals, and other unused propellants. The 9500 lb is the expected average for cases where the Shuttle is delivering a maximum 65,000-lb payload to orbit. With smaller payloads, even more ET propellants will be available—almost pound for pound.

The benefits of recovering these propellants and delivering them to a storage facility on the SOC for later use on OTV missions are enormous. Significant savings in annual Shuttle flights through reduced OTV propellant deliveries are possible.

We have conducted preliminary investigations of the major feasibility issues related to the implementation of this technique. These include trajectory mods to the boost profile and the closely related effects on ET debris impact zones, the various factors affecting cryogenic fluid flow phenomena, some of the transient effects on fluid integrity at MECO, various ullage or propellant settling thrust options and hardware arrangements for the receiver tanks, and plumbing interfaces with the orbiter main propulsion system.

All of these investigations to date have given strong indications of the practical feasibility of performing suborbital recovery of ET propellant residuals or even larger amounts of unused propellants.

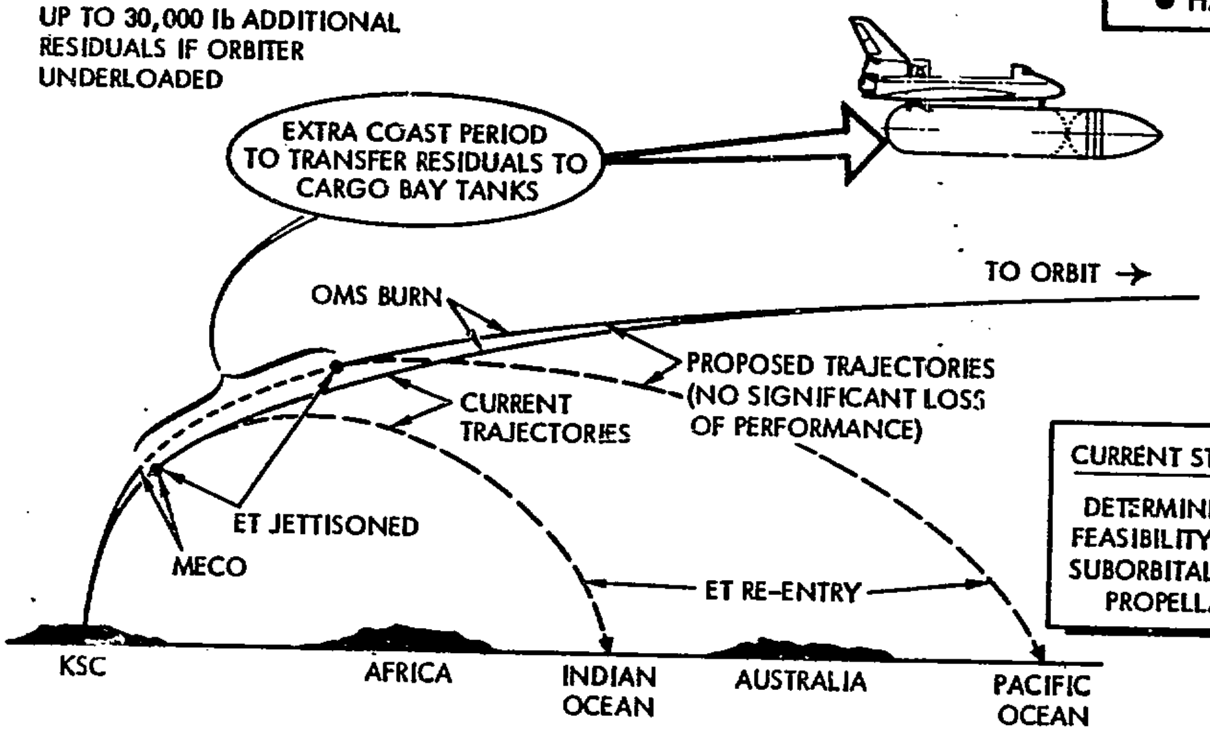
SHUTTLE SYSTEM PROPELLANT SCAVENGING

AVAILABLE RESIDUALS – lb	
FPR	6000
LH_2	900
ET TRAPPED	850
MPS PLUMBING	1800
TOTAL	9550 (± FPR)

NOTE:
UP TO 30,000 lb ADDITIONAL RESIDUALS IF ORBITER UNDERLOADED

PRINCIPAL STUDY AREAS

- TRAJECTORY ANALYSIS
- FLUID TRANSFER PROCESS
- MECO TRANSIENTS
- ULLAGE THRUST OPTIONS
- HARDWARE CONCEPTS



CURRENT STUDY OBJECTIVE

DETERMINE THE PRACTICAL FEASIBILITY OF PERFORMING SUBORBITAL RECOVERY OF ET PROPELLANT RESIDUALS

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TRAJECTORY ANALYSIS

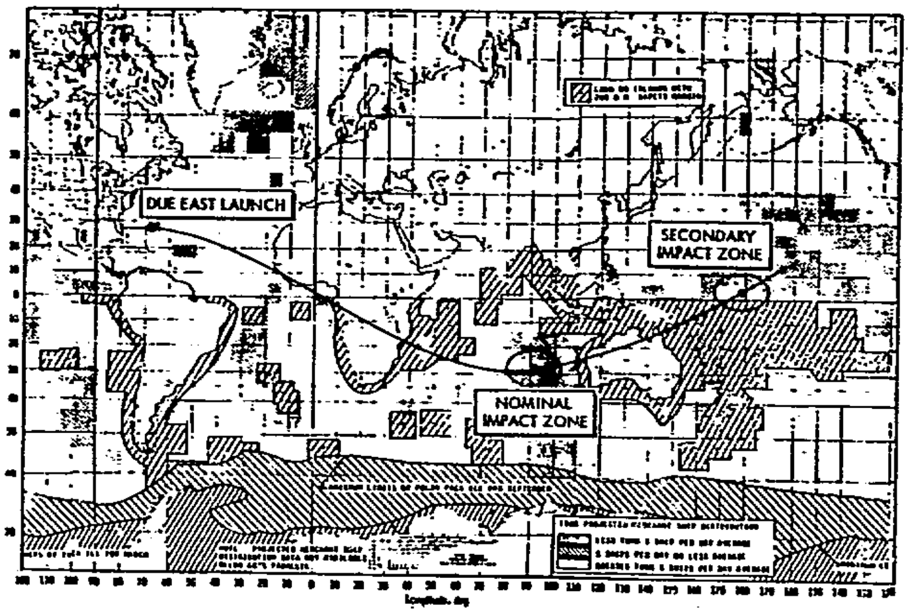
One of the important considerations affecting the feasibility of ET propellant scavenging is the nature and magnitude of the changes which must be made to the Shuttle boost trajectory in order to give sufficient time to perform the propellant transfer operations. The main factors in this analysis are the ullage thrust options (thrust levels employed), the post-MECO time-trajectory relationships and their effects on the ET debris impact zones. As part of these considerations, we were also concerned with how much propellant is needed for ullage thrusting and the combined affects of all factors on Shuttle payload.

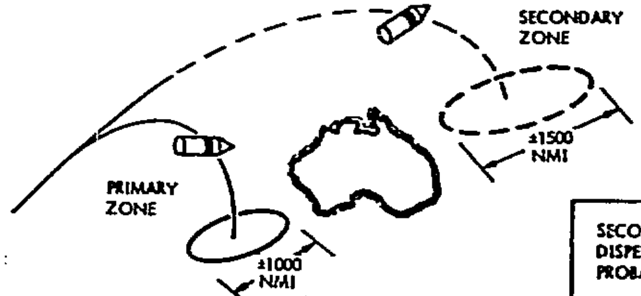
It was determined that a relatively linear relationship exists between the Shuttle burnout velocity at MECO and the amount of ullage thrusting time which could be applied. In essence, ΔV's from ullage thrusting can be used to approximately compensate for small changes in MECO velocity such that ET impacts occur in acceptable zones (primary or secondary) while providing sufficient time for the propellant transfer operations. Up to 20 minutes or more are available for propellant transfer with low thrust ullage options. MECO changes of less than ±1 second (<100 fps bias) in combination with appropriate ullage thrusting periods will meet the ET impact constraints.

It was further determined that the net effects of all factors on the Shuttle payload are negligible. These include the direct effects of changing MECO velocity ($\Delta PL/\Delta V_{MECO}$ - 25.7 lb/fps), the change in OMS propellants for subsequent maneuvers flying the orbiter on up to orbit, and the extra RCS propellants required for ullage thrusting.

These analyses showed boost trajectory solutions to ET propellant recovery requirements are easily possible.

TRAJECTORY ANALYSIS

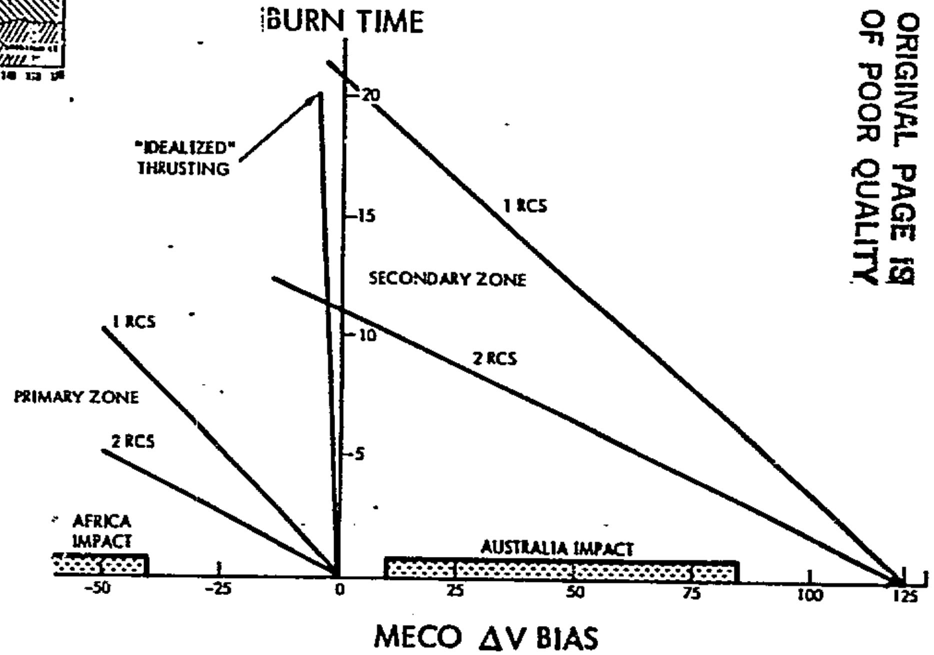




SECONDARY ZONE DISPERSIONS ARE PROBABLY ACCEPTABLE

IMPACT ZONE	NUMBER OF RCS	RCS THRUST (LB)	THRUST TIME (MINUTES)	$\partial R/\partial W$ (NM/%)	$\partial R/\partial C_A$ (NM/%)	$\partial R/\partial V$ (NM/FPS)	$\partial R/\partial \rho$ (NM/%)
SECONDARY	1	870	20.8	10	−8.8	108	−10.1
SECONDARY	2	1740	11.0	6.4	−5.9	63	−6.1
PRIMARY	1	870	5.0	2.8	−2.8	42	−3.0
PRIMARY	2	1740	6.0	2.8	−3.6	43	−3.1

- ET IMPACT SATISFIED
- MECO CHANGES MINOR
- SHUTTLE BOOST TRAJ CONSTRAINTS ARE MET
- NEGLIGIBLE SHUTTLE P/L IMPACTS



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ULLAGE THRUST PROPELLANT REQUIREMENTS

This chart shows the amount of RCS propellants which are required for ullage thrusting as a function of thrusting time. Three thrust options are shown: (1) dual RCS, (2) single RCS (alternate left-right firing), and (3) an "idealized" case with thrust equal to drag plus 50 lb. Aerodynamic drag at MECO ranges from 10 to 30 or 40 lb, and decays rapidly to less than 1 lb. Thus, the idealized case is essentially 50 lb of continuous thrust.

The dual RCS case is shown to require over 8000 lb of propellant for a thrust period of 20 minutes. Propellant consumption is 414 lb/minute and includes an 11% factor for attitude control. Single RCS consumption would be one-half this amount (207 lb/minute), while the idealized case would use only 11.5 lb/minute.

The amount of RCS propellant available after other maneuvers required for ascent/descent and mission operations is shown to be 1604 lb. Propellant needs beyond this amount can be met by utilizing the OMS cross-feed capability. Here, propellant from the OMS tanks can be transferred to the RCS system for use by the RCS thrusters. Ample OMS propellant exists to meet all of the ullage thrust options, but propellant amounts over the 1604 lb available in the RCS system would reduce the Shuttle payload. The low-thrust options for ullage thrusting fall well within the 1604-lb limit.

Thus, propellant availability for ullage thrusting is not a serious problem.

ULLAGE THRUST PROPELLANT REQUIREMENTS

RCS PROPELLANT BUDGET, LB	
ASCENT/DESCENT	(3398)
INSERTION AND ORBIT ADJUST	1127
ENTRY	1164
RESIDUALS AND CONTINGENCIES	1107
MISSION OPERATIONS	(1450)
RENDEZVOUS	1450
TOTAL	4848

TOTAL PROPELLANT LOADED
7254 LB

AVAILABLE FOR ULLAGE THRUST
7254-4848 = 2406 LB

2/3 IN AFT QUADS = 1604 LB

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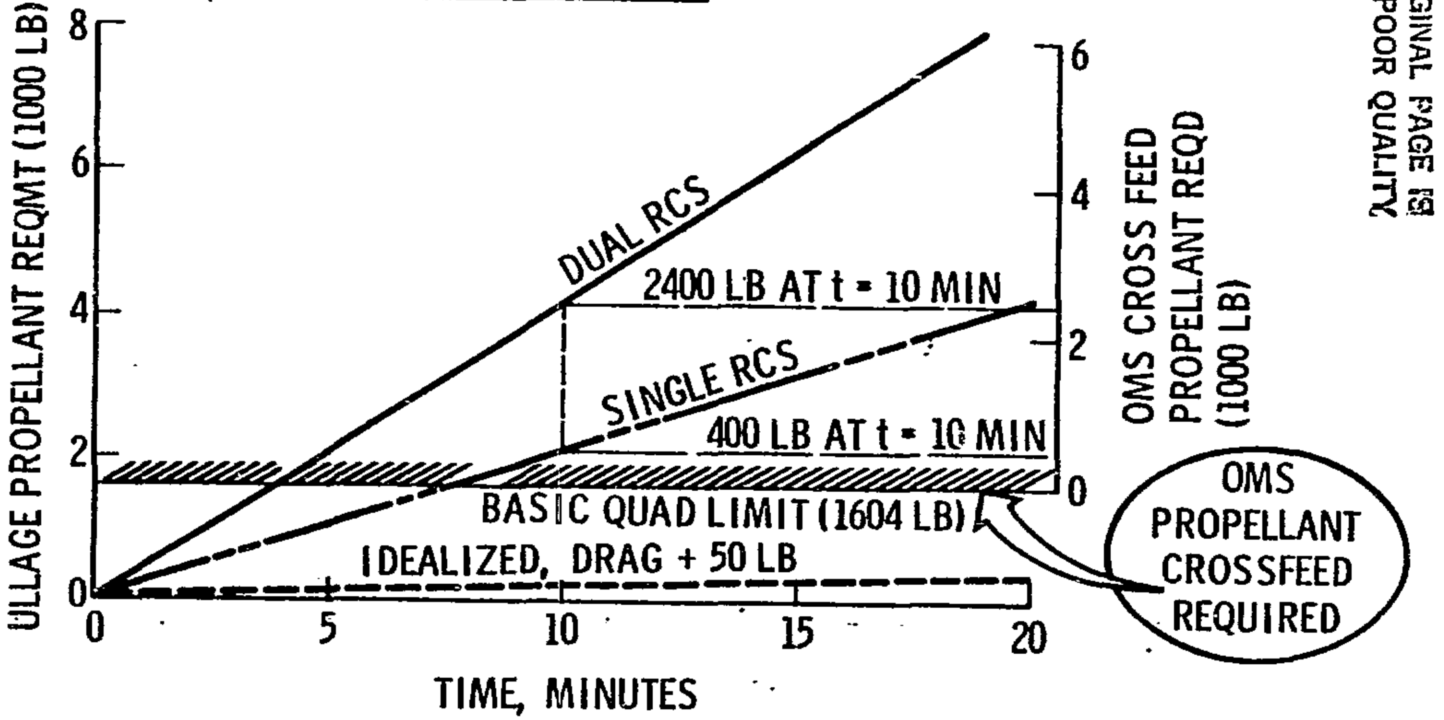


The transfer process in moving the propellants from the ET to receiver tanks in the orbiter is affected by many factors. The focal point for all of these effects is the pressure differential between the ET and the receiver tank.

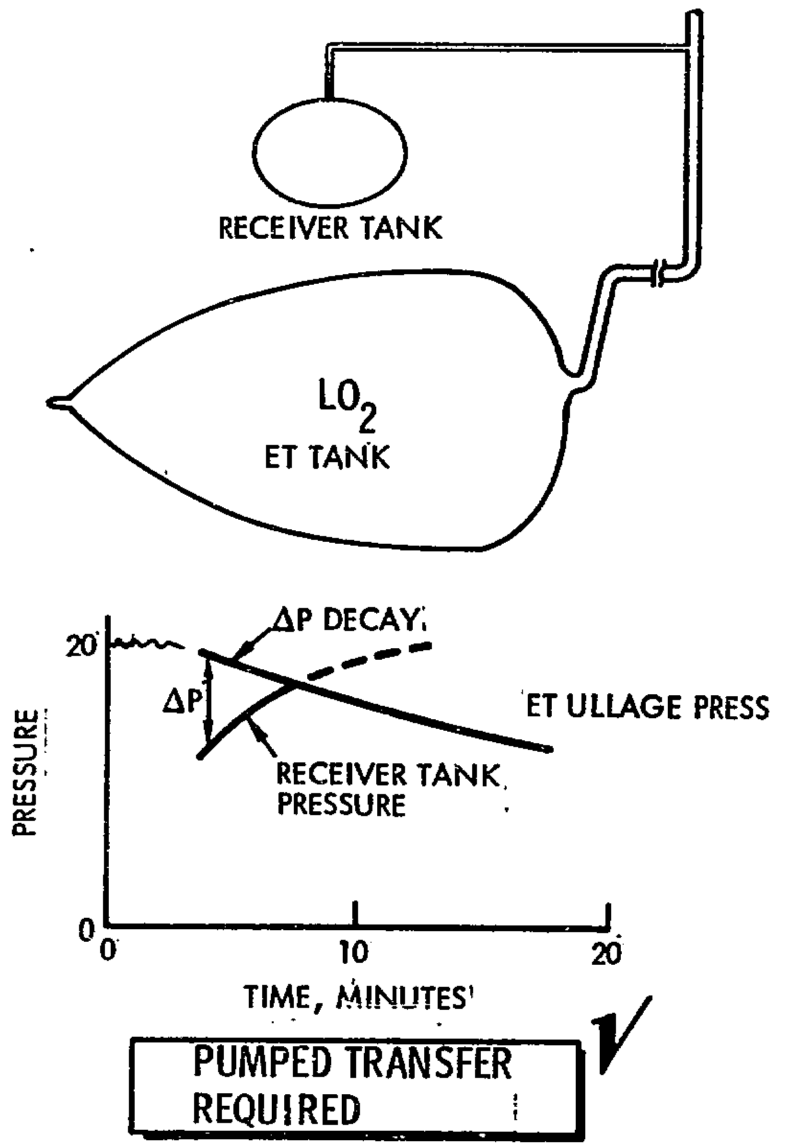
The LO_2 and LH_2 tanks in the ET are pressurized by "bleed gas" loops in their respective systems. These "hot" gasses are fed back into the ET during boost to maintain sufficient system pressure to avoid cavitating the turbopumps feeding the main engines. The required tank pressures are approximately 20 and 32 psia for the LO_2 and LH_2 tanks respectively. At MECO the pressurization system is shut off and the vapor in the tanks is cooled by contact with the relatively cool tank walls and by residual liquid propellants in the tank. This cooling process causes the pressure in the ET tanks to decay; the rate of decay is affected by ullage thrust levels, high thrust produces faster ET pressure decay.

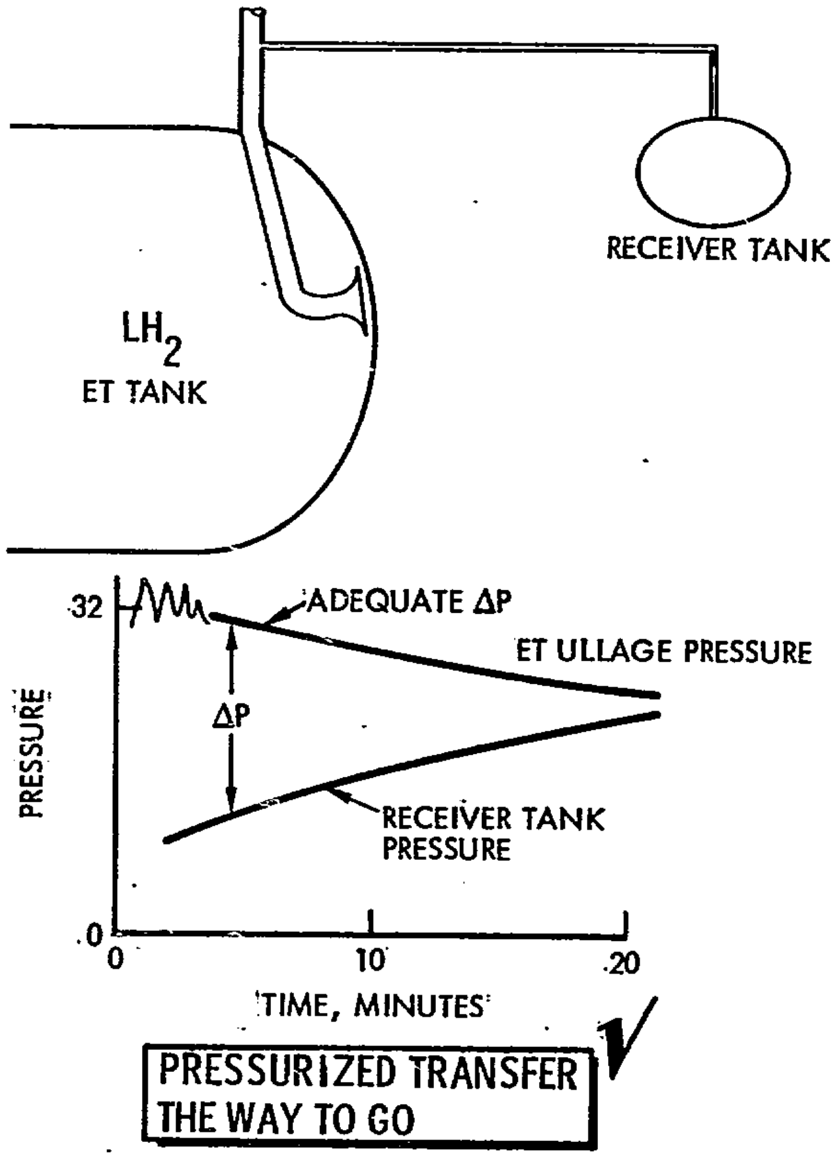
In contrast to the ET tanks above, the pressure environment in the receiver tanks rises with time. After the initial pressure surge for tank chilldown this pressure rise is due to the heat leaks into the system. In the LO_2 system significant heat inputs occur from the boost heated belly tiles of the orbiter along the LO_2 feedline and heat soakback from the main engines and plumbing. The LH_2 system is also heated by engine soakback, but also receives considerable heating from the aft bulkhead which can be exposed to direct solar heating at MECO. Thus, receiver tank pressures rises with time.

In the case of LH_2 transfer the starting pressure (32 psia) is sufficiently high that an adequate pressure differential exists to perform pressurized transfer within reasonable periods of time (up to 10 or 20 minutes).

The low starting pressure for LO_2, however, imposes the requirement for pumped transfer. Pressurized transfer of nominal amounts of LO_2 could probably be made to work, but for wider applications of the scavenging techniques and to gain higher technical confidence, a pumped LO_2 transfer approach is preferred.

PROPELLANT TRANSFER PROCESS





PRACTICAL SCAVENGING CONCEPTS

This chart depicts some of the main hardware considerations pertinent to ET propellant scavenging. First, there are a number of possible ullage thrust options. Ullage thrusting is required to keep the residual propellants settled at the bottom of tanks. Analysis has shown that existing primary RCS thrusters can be used, although propellant comsumption can be greatly reduced by adding vernier thrusters to fire in the X-direction (the current verniers do not thrust in this direction). Thus, practical solutions to ullage thrusting are possible.

Analysis has also shown that 4 inch transfer lines will be sufficient to perform the basic propellant flow process. With this line size a pump must be used in the LO_2 transfer system. Modified centaur pumps can be used for this application, but smaller capacity pumps of new design would use less electrical power. Preliminary looks indicate ample space is available in the orbiter engine compartment to install these elements. Thus, practical pumping solutions are possible.

A number of receiver tank options were explored, both internal and external to the orbiter. Some of the external options could probably be made to work, but would have significant orbiter design impacts. Internal designs ranging from convential, easy to install tanks to more advanced torus configuration were determined to have capabilities ranging from 10,000 to 30,000 pounds (sized for a 6:1 mixture ratio and to fit the OMS kit length of 9 feet). The enormous benefit potential of the propellant scavenging concept suggests an optimum tank concept leaning toward the advanced designs would be highly appropriate. Regardless of the final tanking concept selected, practical solutions are possible.

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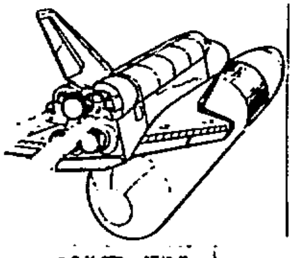
PRACTICAL SCAVENGING CONCEPTS

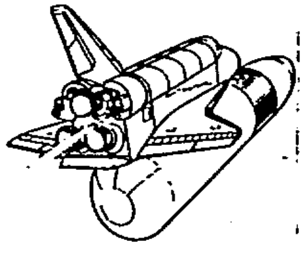
ULLAGE THRUST OPTIONS

DUAL PRCS THRUSTERS



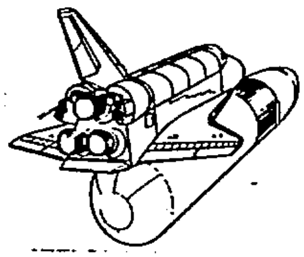
- 2 X 870 = 1740 lb_f
- T/W = 0.0047 g's
- $\dot{w}_p \approx$ 414 lb/min
- MINIMUM ORBITER IMPACT

SINGLE PRCS THRUSTER

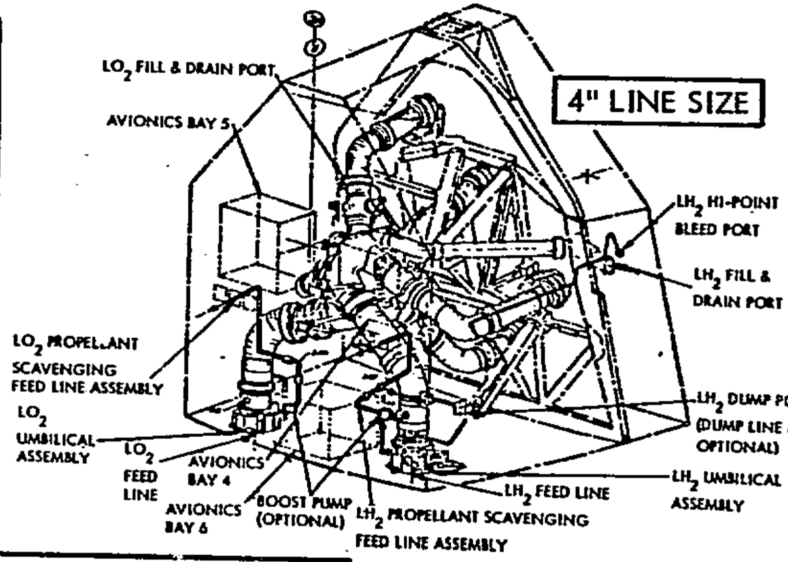


- 1 X 870 = 870 lb_f
- T/W = 0.0024 g's
- $\dot{w}_p \approx$ 207 lb/min
- ATTITUDE CONTROL SOFTWARE MOD

ADDED VERNIER THRUSTERS

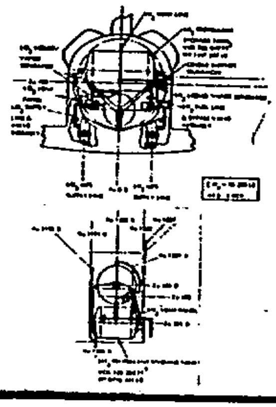


- $T_{INITIAL}$ = 2 X 870 = 1740 lb_f (APPROX. 40 - 60 sec)
- T_{FINAL} = DRAG + 50 lb_f
- T/W $\approx 10^{-4}$ g's
- $\dot{w}_p \approx$ 11.5 lb/min
- HARDWARE & SOFTWARE MODS

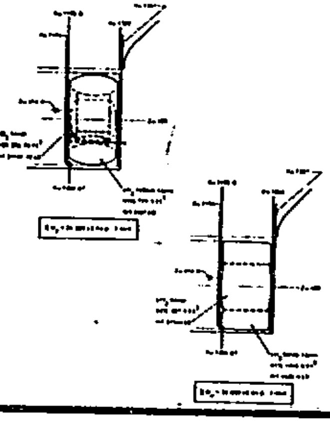


HARDWARE CONCEPTS

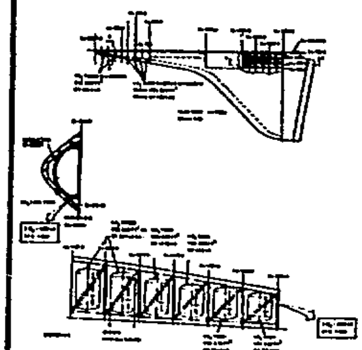
CONVENTIONAL



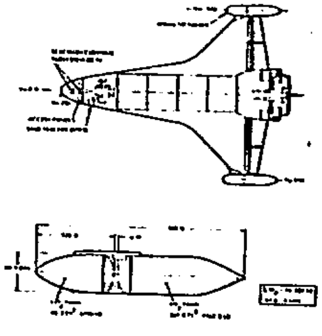
TORUS



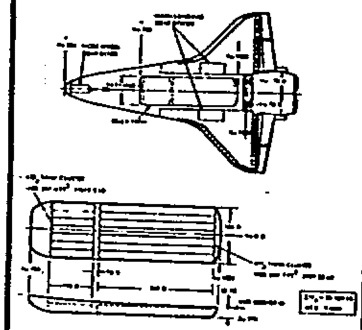
WING INTERNAL



TIP TANKS



BELLY TANKS

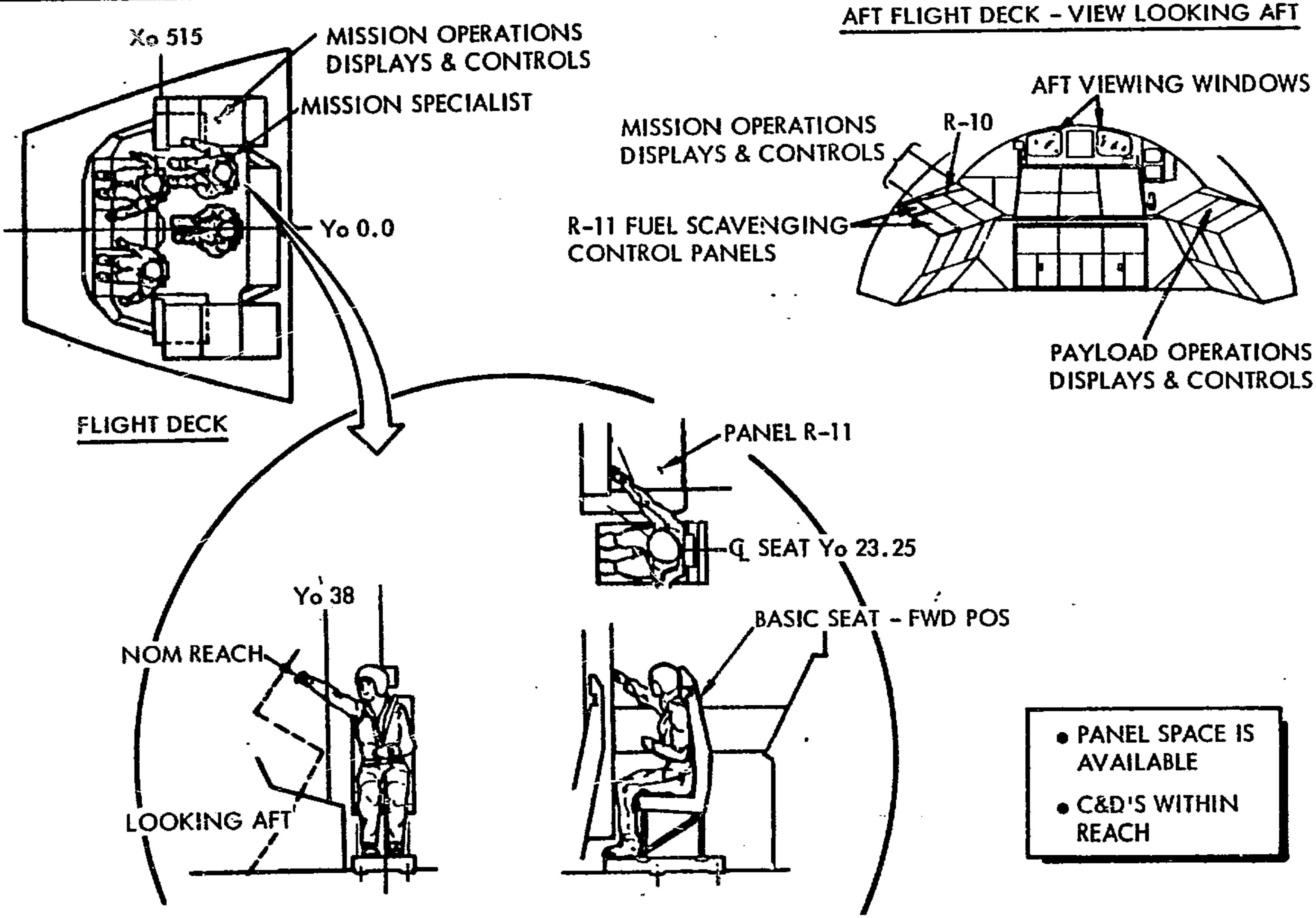


CREW CONSIDERATIONS

It is envisioned that the orbiter crew would play an active role in the ET propellant scavenging operations. Given the ability to monitor temperatures, pressures, flow rates and fluid characteristics probably the simplest transfer concept would involve crew participation. Further studies are required to define the specific nature of the crew requirements and the degree of automation to be introduced into the flow process.

For our preliminary look, here, it has been determined that control panel space is available for appropriate flow monitor and control functions. Further, this panel area (panel R-11) is within the reach envelope of the mission specialist from his seated position at MECO. Thus, crew participation in the transfer process appears possible. Additional study is required to determine the transition effects on crew capabilities from the boost environment to zero-g. However, fighter pilots frequently perform in this type of environment so crew participation in the flow control process appears feasible.

CREW CONSIDERATIONS



- PANEL SPACE IS AVAILABLE
- C&D'S WITHIN REACH

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NOMINAL PROPELLANT RESIDUALS AT MECO

The amount of propellant remaining in the ET at the end of boost is dependept upon how much payload was carried to orbit. Aside from the flight performance reserves and residuals trapped in the system the ET will contain an additional 0.95 pounds of propellants for every pound of unused payload capacity that might exist on a given flight manifest.

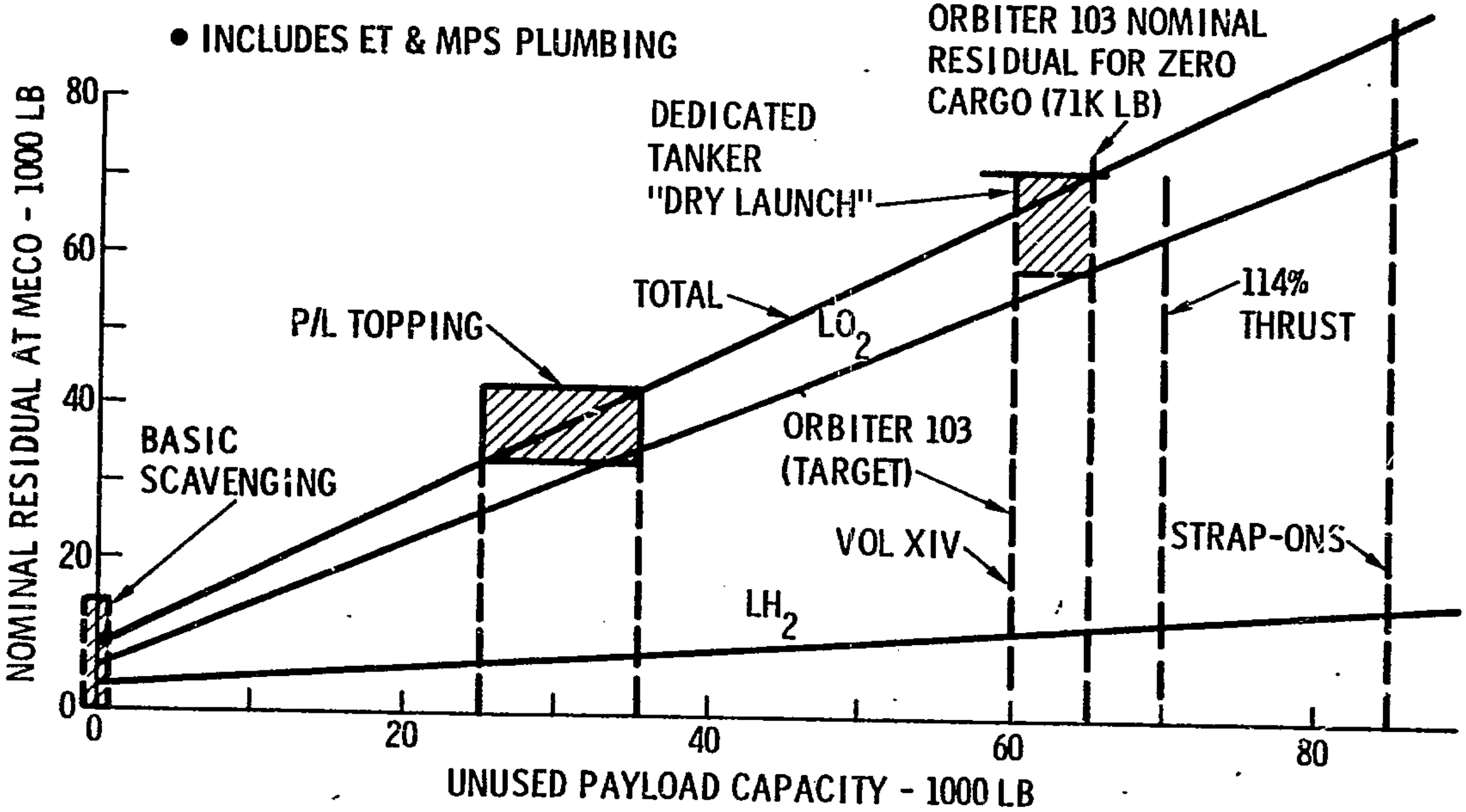
The relationship betweel LO_2, LH_2 and total propellants remaining and the Shuttle unused payload capacity is shown in the accompanying chart. Values of propellant remaining can be up to 80,000 pounds or even higher depending upon future Shuttle improvements and/or growth options.

Superimposed on these propellant/payload relationships are three possible scavenging scenarios. These range from the "basic scavenging" situation in which only the nominal rediduals remaining after a full payload launch are recovered. The second scenario reflects the density characteristics of most dry cargo manifests. Hard cargos approximately filling the orbiter bay tend to weigh about 30,000 pounds. This type of payload manifest could either be "topped off" on the ground with propellants to bring the total payload up to the orbiter capacity or the system could be "dry" launched and the 30,000 to 40,000 pounds of remaining propellants scavenged similar to the case above.

In the third scenario we carry the "dry" launch concept all the way to a dedicated tanker flight. Here, instead of launching the orbiter with a full cargo of propellant the tanker is launched empty and the full 71,000 pounds (theoretical maximum) of propellants would be recovered through scavenging operations.

Thus, a wide range of scavenging scenarios is possible.

NOMINAL PROPELLANT RESIDUALS AT MECO



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SCAVENGING ANALYSIS SUMMARY

All analysis to date have indicated that suborbital recovery of unused ET propellants is a viable concept with enormous benefits to the SOC operational scenario.

Trajectory analyses have shown ET debris impact constraints can be satisfied with minor ΔV biases at MECO for a wide range of ullage thrust options including the use of existing primary RCS thrusters. All of these solutions provide ample time for the propellant transfer operations and are within RCS propellant budget limits.

Practical hardware concepts for receiver tanks and plumbing are achievable within the space/volume constraints of the orbiter engine compartment. MECO transient effects and fluid flow phenomena can all be satisfied with practical control and design solutions.

The MECO changes and subsequent flight maneuvers have negligible effects on Shuttle payload capability.

The system can be designed and qualified to meet the safety standards currently applied to the Shuttle system. Scavenging is a post MECO operation which would not jeopardize earlier main engine operations.

A wide range of scavenging applications are possible. We can safely and efficiently recover propellant amounts ranging from the 9,500 pound expected for Shuttles launched with maximum payloads up to 70,000 pounds or more for the dedicated tanker "dry launch" concept where the orbiter is launched with an empty tank (no other payload) and all the ET propellants remaining are transferred via scavenging operations.

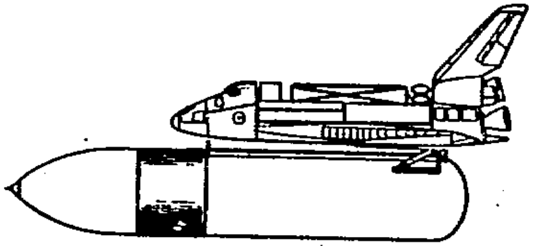
Thus, ET propellant scavenging is judged to be a viable and desirable concept.

SCAVENGING ANALYSIS SUMMARY

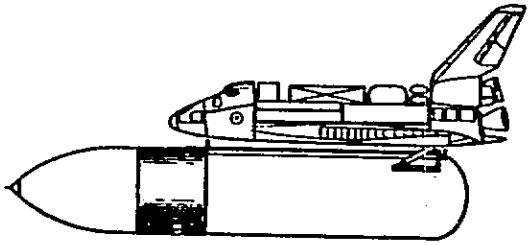
ET PROPELLANT SCAVENGING IS FEASIBLE √

WIDE RANGE OF SCAVENGING SCENARIOS ARE POSSIBLE √

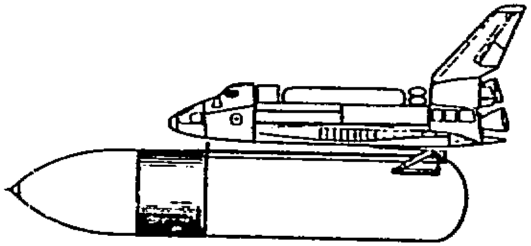
- BASIC SCAVENGING
- P/L TOP-OFF
- DEDICATED TANKER



$w_P \approx$ 10-15K LB



$w_P \approx$ 30-40K LB

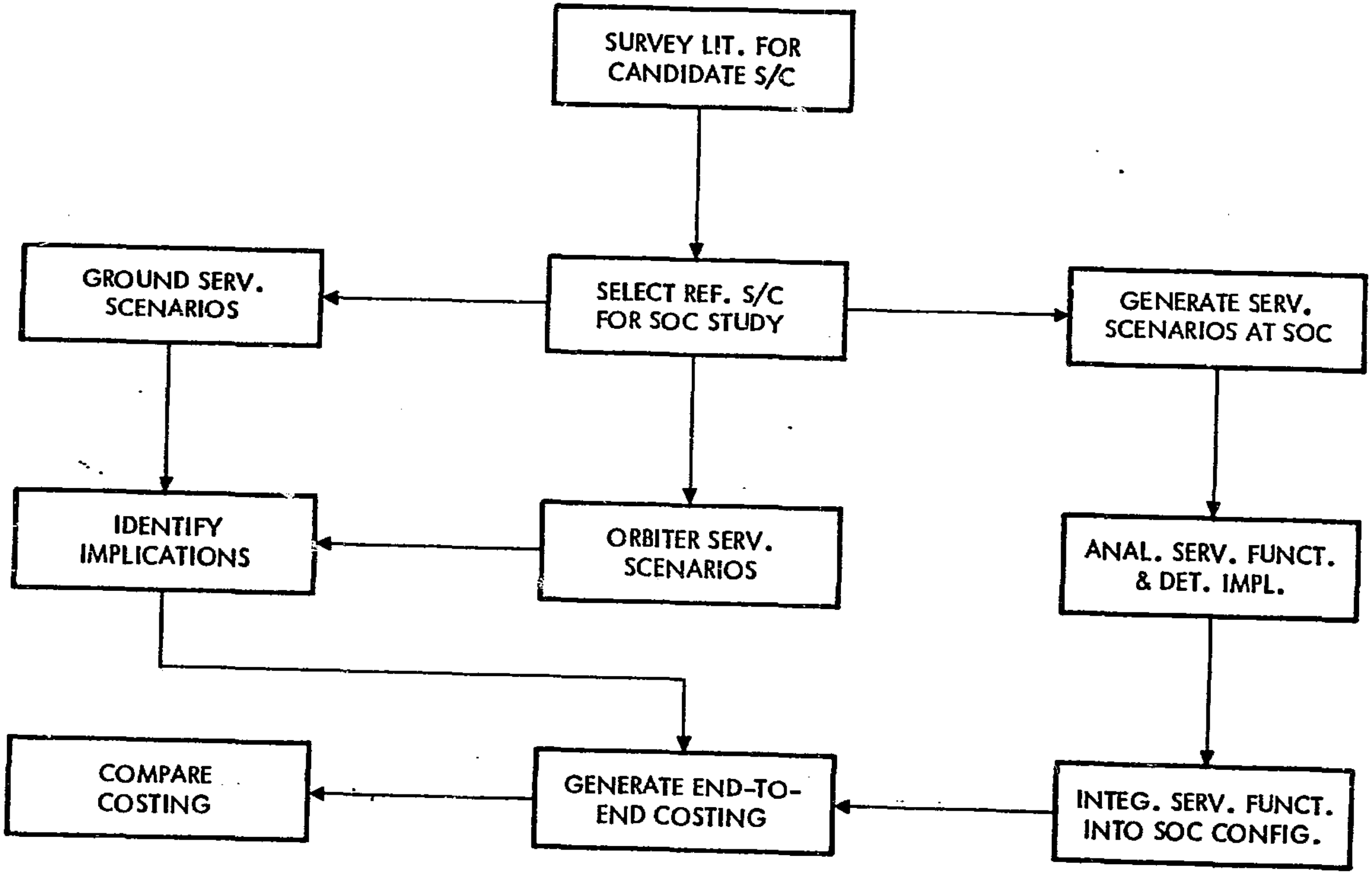


$w_P \approx$ 70 + KLB

TASK 4—FLIGHT SUPPORT FACILITY

To accomplish this task, our approach is to select several representative spacecraft and analyze their servicing requirements if they are to be serviced by the SOC, by the orbiter, and on the ground. From the analysis, implications to the SOC, the orbiter, and the spacecraft will be determined. For the SOC, the implications will lead to a preliminary integrated configuration of the Flight Support Facility. Furthermore, the implications, along with those of ground servicing and orbiter servicing, will serve as the basis for generating end-to-end costing of the servicing functions and comparison of the costs of the various servicing methods.

TASK 4 -- FLIGHT SUPPORT FACILITY



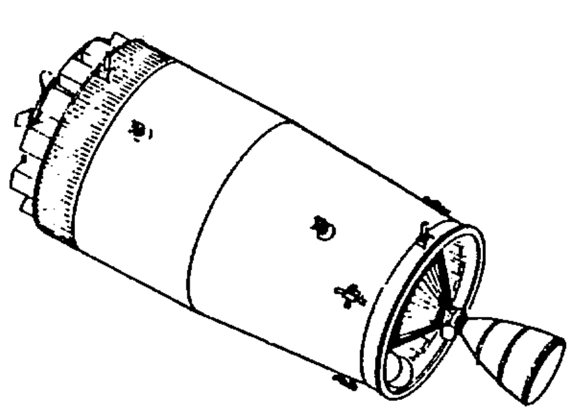
REPRESENTATIVE SPACECRAFT

To determine the implications and drive out the required servicing provisions of the SOC Flight Support Facility, three spacecraft were selected for detailed analysis. These spacecraft are characterized by many subsystems and features that are likely to be included on many of the spacecraft that are expected to be serviced by the SOC. Consequently, the diversity of these subsystems and features was the main contributor to their selection. The OTV is a cryogenic stage that also uses hydrazine for its RCS. In addition, it utilizes helium and gaseous nitrogen for various pneumatic valve actuation, pressurization, and purge systems. This spectrum of fluids must be supplied through the SOC Flight Support Facility and, consequently, will dictate the required provisions for fluid loading operations.

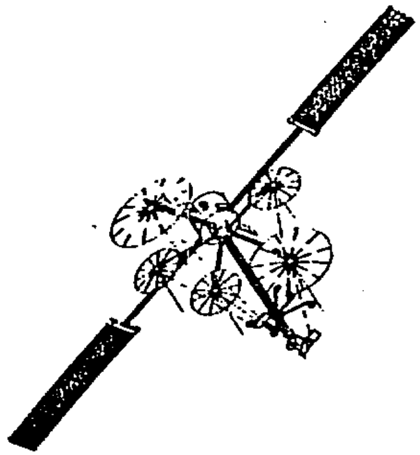
The communication satellite is a relatively large spacecraft that requires extensive deployment and checkout operations and final mating to the OTV for launch to GEO. The Space Processing Facility is smaller in size and its servicing requirements consist mainly of refueling and module exchange operations during frequent revisits to the SOC.

To scope the analysis of servicing these spacecraft, six scenarios were selected for estimating servicing man-hours and final cost comparisons. For the OTV, ground and SOC servicing scenarios were analyzed. The other two spacecraft were considered in terms of orbiter and SOC servicing. It is noted that servicing the communication satellite consists mainly of initial deployment, mating to the OTV, and launch to GEO. Once launched, it will not revisit SOC.

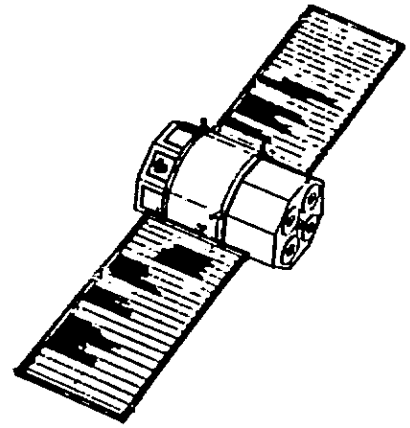
REPRESENTATIVE SPACECRAFTS



OTV



COMMUNICATION SATELLITE



SPACE PROCESSING FACILITY

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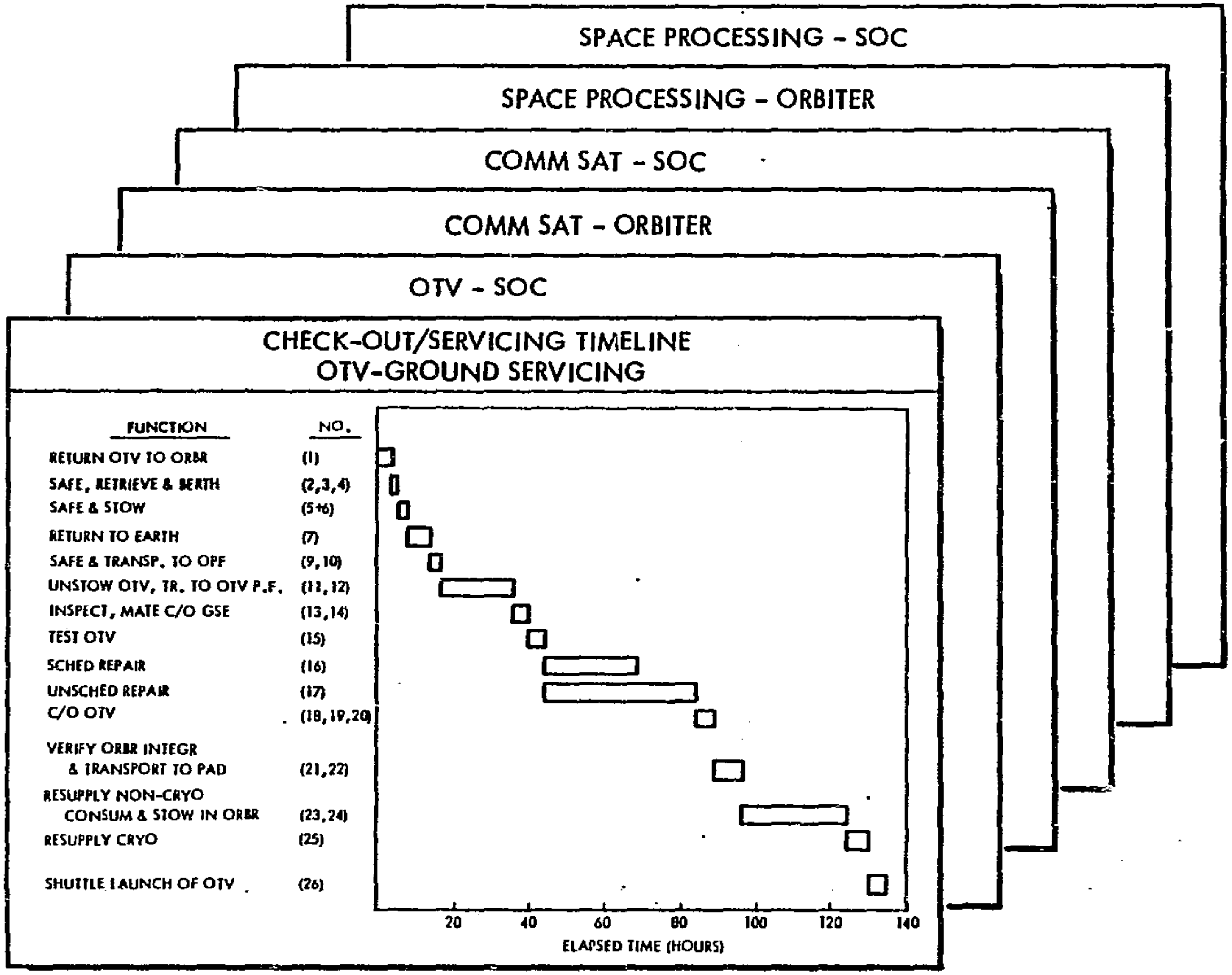
- FEATURES SIGNIFICANT TO SERVICING
  - LOADING OF FLUIDS
    - CRYOGENICS - LO_2, LH_2
    - NON-CRYOGENICS - He, GN_2, HYDRAZINE
  - MODULE & COMPONENT EXCHANGE OPS
  - EXTENSIVE DEPLOYMENT & C/O OPS
  - FREQUENT REVISITS
  - SMALL TO LARGE S/C

S/C	GROUND SERVICING	ORBITER SERVICING	SOC SERVICING
OTV	✓	N/A	✓
COMM SAT	N/A	✓ INITIAL ASSY & LAUNCH TO GEO	✓ INITIAL ASSY & LAUNCH TO GEO
SPACE PROCESSING FACILITY	N/A	✓	✓

CHECKOUT/SERVICING MAN-HOURS

Detailed activities for the six selected servicing scenarios were individually generated and analyzed in terms of functions that are required to turn-around the spacecraft within assumed servicing boundaries. Subsequently, timelines were estimated to perform the servicing functions as illustrated on this chart. A summary of the results is presented on the next chart.

CHECK-OUT SERVICING MANHOURS



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CHECKOUT/SERVICING MAN-HOURS SUMMARY

The results of the timeline estimates show that the difference between the elapsed time required to service the communication satellite from the SOC and that of servicing it from the orbiter is very small. Similar results are indicated for the Space Processing Facility. However, servicing the OTV on the ground requires considerably more time than servicing it on the SOC. The difference is attributed mainly to the design philosophy that was assumed for each of the OTV servicing scenarios. For the ground-designed OTV, a scenario without SOC or in-space fueling provisions was assumed which necessitated launching the OTV in the fueled state. To accommodate this mass-sensitive condition, a conventional aerospace structural design was assumed that could not afford the weight penalties associated with extensive servicing accessibility provisions or remote module exchange operations. In addition, ground servicing implies considerable transportation timelines where the OTV must be moved from one dedicated servicing facility to another. These constraints do not exist for the SOC servicing scenario where the space-designed OTV was assumed to be launched in the unfueled condition. As a non-weight-sensitive payload, weight penalties of accessibility provisions and remote/automatic component/module exchange operations are more tolerable.

CHECK-OUT/SERVICING MANHOURS SUMMARY

LOCATION	ELAPSED TIME	MAN-HOURS	NO. CREW	
			RANGE	AVG
OTV - GROUND	134.0	576.0	3 - 6	4.3
OTV - SOC	26.3	99.7	3 - 5	3.8
COMM SAT - ORBITER	50.8	164.8	2 - 4	2.4
COMM SAT - SOC	61.0	199.6	2 - 5	2.6
SPACE PROCESSING - ORBITER	27.5	106.0	2 - 4	3.5
SPACE PROCESSING - SOC	29.6	103.4	3 - 4	3.5

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OTV-SOC SERVICING IMPLICATIONS:

Analysis of the turnaround functions and activities for each of the selected servicing scenarios implied a general set of required provisions and equipment to perform the servicing operations. This chart presents a summary of the particular set concerned with OTV servicing on the SOC. Similar sets were identified for each of the remaining servicing scenarios.

OTV-SOC SERVICING IMPLICATIONS

SUMMARY OF REQUIRED SERVICE PROVISIONS & EQUIPMENT

OTV	SOC
• REMOTE SAFING SYSTEM	• OTV CONTROL & MONITOR STATION
• COMMUNICATION & DATA LINK TO SOC & GROUND OCC	• COMMUNICATION & DATA LINKS TO OTV & ITS GROUND OCC
• NON-PROPULSIVE VENT SYSTEM	• ACTIVE DOCKING PORT ON FSF WITH ALIGNMENT MONITORING SYSTEM
• DOCKING PORT WITH ALIGNMENT TARGET	• EXTENDABLE NON-PROPULSIVE BOOM
• OTV-SOC SYSTEM INTERFACES (3-FLUID & 1-ELECT). WITH DUAL QUICK DISCONNECTS	• MOBILE MANIPULATORS (2) WITH STD END EFFECTOR & SPEE
• OTV-SOC STRUCTURAL INTERFACES (2 PIDA DEVICES)	• CCTV CAMERA ON MOBILE MANIPULATORS
• OTV-SOC MANIPULATOR INTERFACES (2 GRAPPLE FIXTURES)	• OPEN CHERRY PICKER & MMU
• ACCESSIBLE COMPONENT DESIGN	• RETRACTABLE UMBILICALS -- 3 FLUID & 1 ELECT
	• LRU STORAGE & RETRIEVAL SYSTEM

CONCLUSIONS AND PLANS

- FLEET UTILIZATION ANALYSIS HAS BEEN STARTED...
  - IMPORTANT RESULTS ARE EXPECTED
- SOC ASSEMBLY ANALYSIS UNDERWAY...
  - COMPUTER INTERACTIVE GRAPHICS WILL GIVE HIGH CONFIDENCE TO CLEARANCE GEOMETRIES
- ET PROPELLANT SCAVENGING PROVEN FEASIBLE...
  - AMPLE TRANSFER TIME
  - ET IMPACT SATISFIED
  - NO SIGNIFICANT STS PAYLOAD IMPACT
  - ACCEPTABLE SAFETY STANDARDS CAN BE MET
  - WIDE RANGE OF APPLICATION SCENARIOS IS POSSIBLE
- FLIGHT SUPPORT FACILITY ANALYSIS WELL UNDERWAY...
  - SERVICING IMPLICATIONS IDENTIFIED
  - SERVICING TIMELINES AND COST DATA ARE BEING GENERATED
  - KEY INSIGHTS INTO COST EFFECTIVENESS OF VARIOUS SERVICING SCENARIOS WILL BE GAINED

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EXECUTIVE SUMMARY

FLEET UTILIZATION ANALYSIS

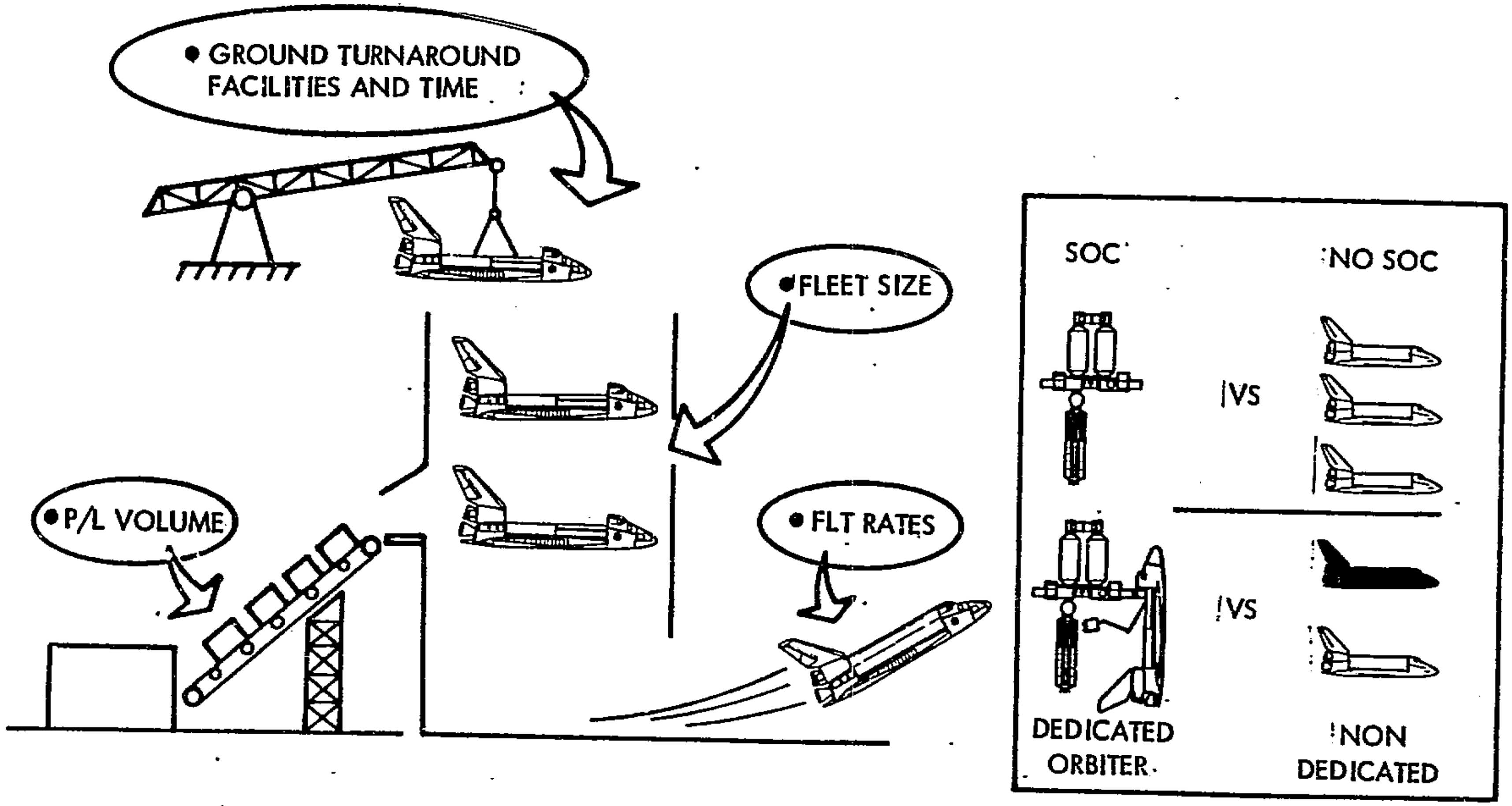
SHUTTLE SYSTEM PROPELLANT SCAVENGING

SOC ASSEMBLY OPERATIONS

FLIGHT SUPPORT FACILITY

CONCLUSIONS & PLANS

FLEET UTILIZATION ANALYSIS



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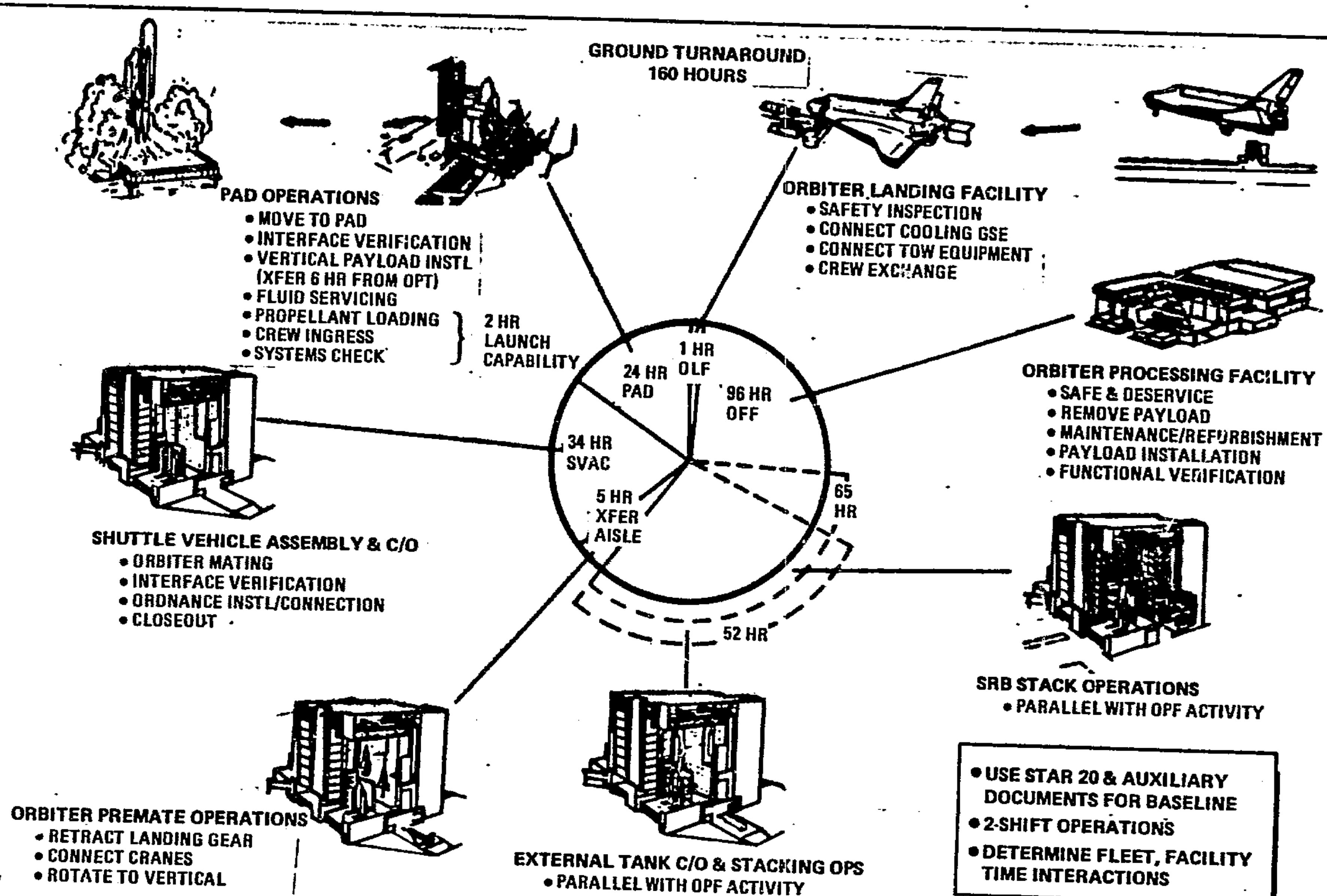
SHUTTLE TURNAROUND ANALYSIS



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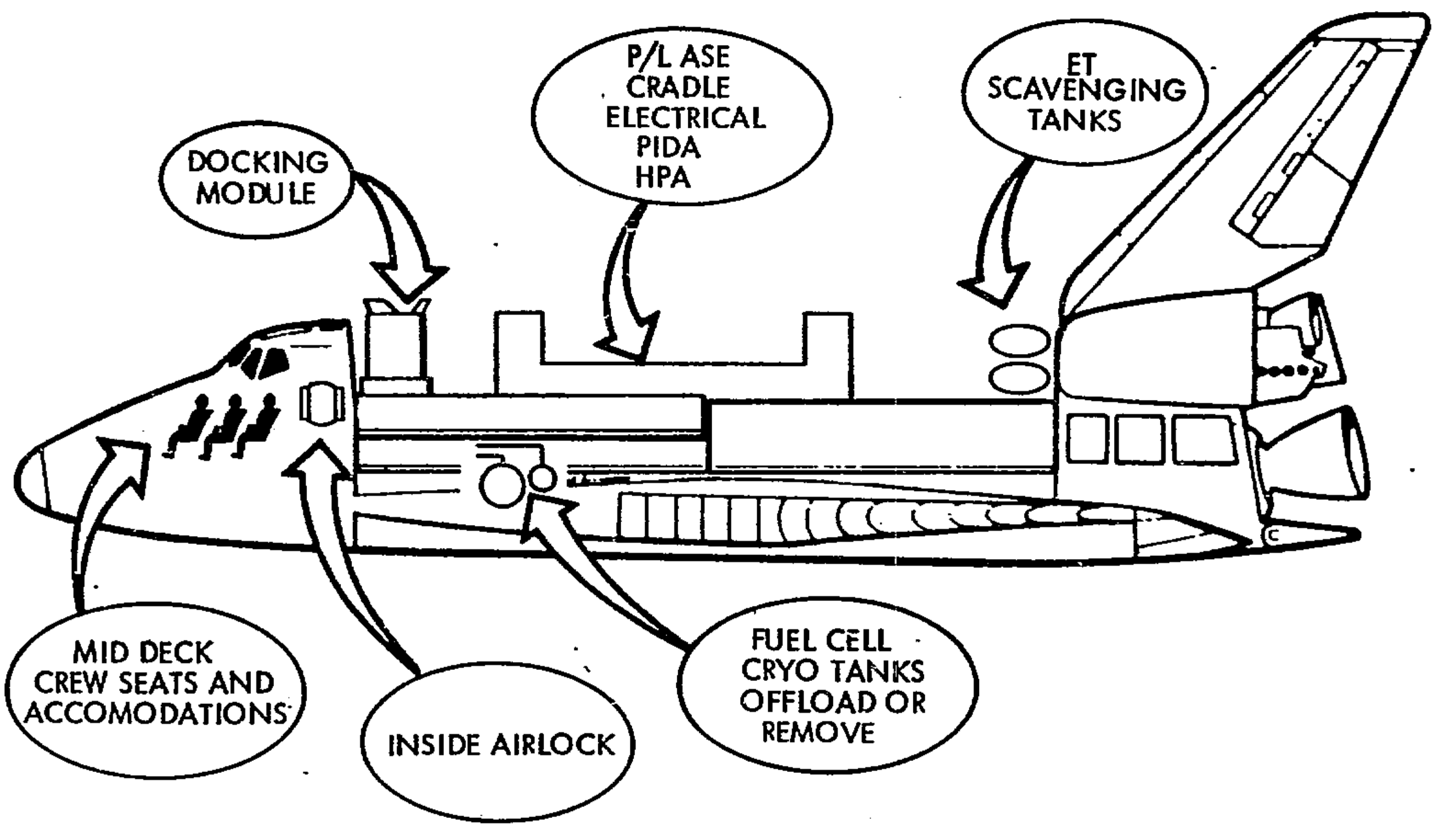
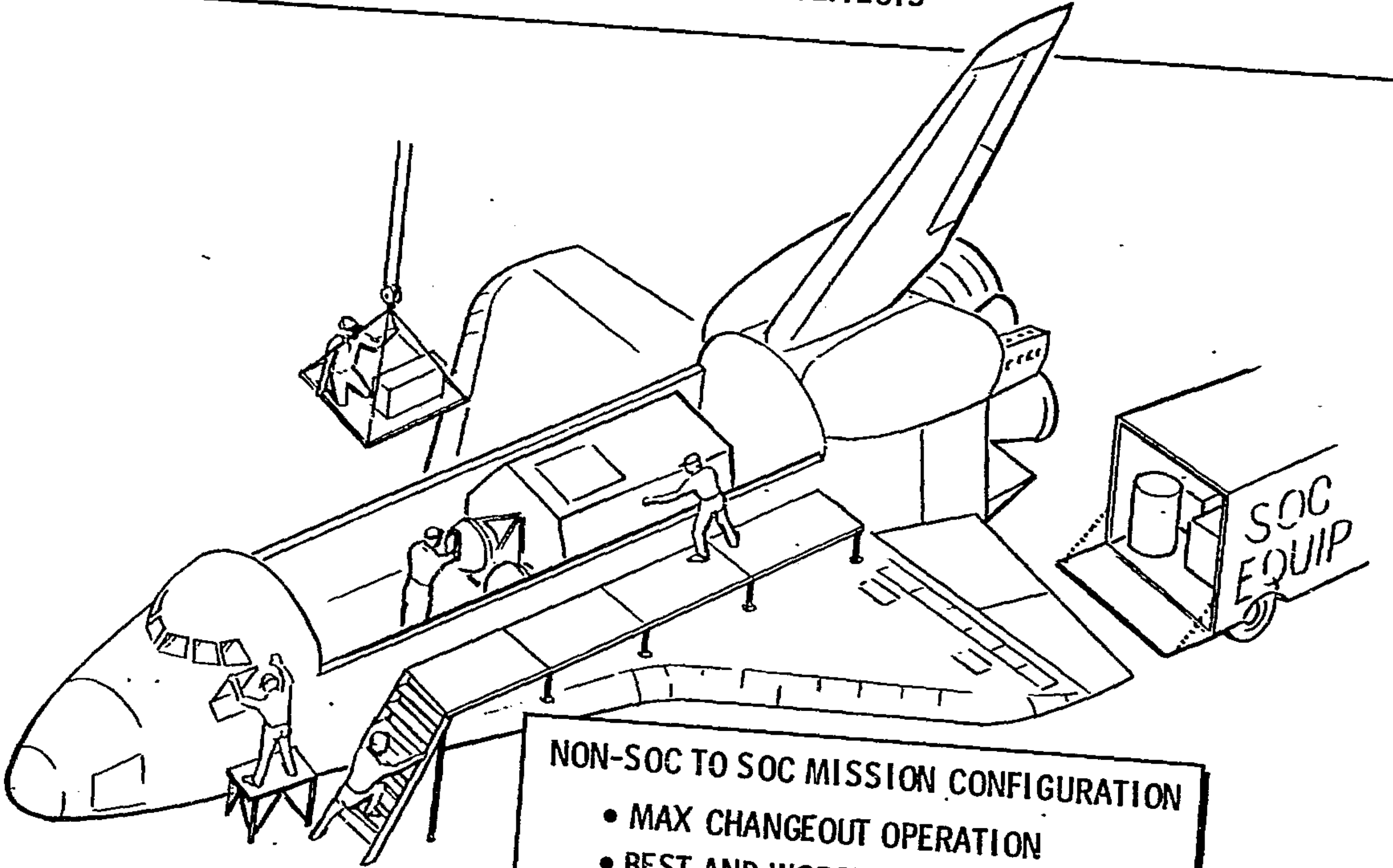
- USE STAR 20 & AUXILIARY DOCUMENTS FOR BASELINE
- 2-SHIFT OPERATIONS
- DETERMINE FLEET, FACILITY TIME INTERACTIONS

DEDICATED ORBITER CONSIDERATIONS



DEDICATED ORBITER EFFECTS



NON-SOC TO SOC MISSION CONFIGURATION

- MAX CHANGEOUT OPERATION
- BEST AND WORST MISSION SCHEDULES
- RANGE OF TRAFFIC LEVELS

SOC VS NO SOC

SPACE PROGRAM REQMTS
MISSION MODEL

TRADE

SOC

- SOC SUPPORT REQMTS
- MANIFEST RULES FOR SOC
  - P/L TOPPING
  - ET PROPELLANT SCAVENGING
  - SOC INTERFACE EQUIP
- MISSION SCHEDULING RULES
  - OTV AND PROPELLANT AVAILABILITY
  - SPLIT P/L DELIVERIES

VS

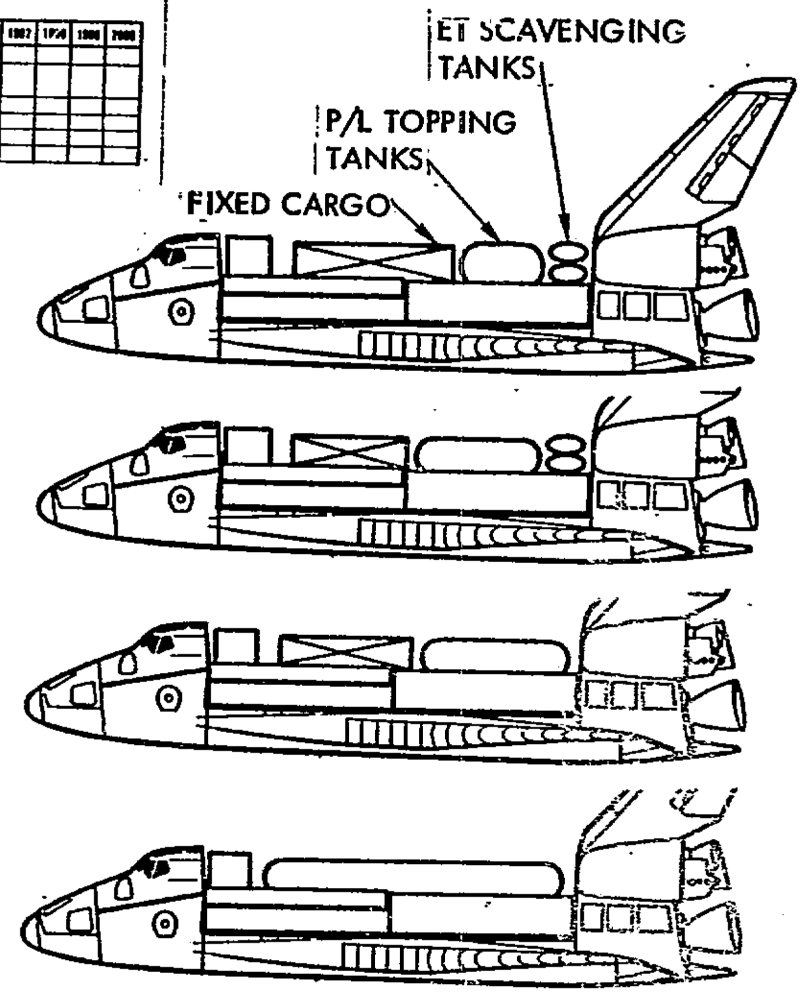
NO SOC

- MISSION SUPPORT REQMTS
  UNIQUE EQUIPMENT
  SPECIAL OPERATIONS
- MANIFEST RULES FOR NON-SOC OPERATIONS
  - P/L CAPABILITY TO DESTINATION ORBITS
  - P/L SHARING CONSTRAINTS
- MISSION SCHEDULING RULES
  - MULTI-SHUTTLE MISSIONS
  - LAUNCH WINDOW CONSTRAINTS
  - MISSION DURATION

SOC PROPELLANT DELIVERY OPTIONS

TRAFFIC MODEL

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
COMMERCIAL	4	5	7	8							
SCIENCE AND APPLICA	1	1	2	3							
DOD	3	6	7	8							



ISSUES

- SIZE RANGE OF P/L TOPPING TANKS
- COMBINED P/L TOPPING & ET SCANVENGE TANKS
- POSSIBILITY OF LAUNCH "DRY" CONCEPT

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REFERENCE TRAFFIC MODEL CONSTRUCTION

BASIC MISSION ANALYSIS

- COMMERCIAL
- NASA
- DOD

- GROUND RULES AND ASSUMPTIONS
- SPACE PROGRAM LEVELS
- HI - LO MIX
- MANIFEST DEFINITION AND SCHEDULES

TOTAL SPACE TRAFFIC

	1982	• •	• •	2000
COMMERCIAL				
NASA				
DOD				
TOTAL				641

SOC RELATED TRAFFIC

	1990	• •	• •	2000
COMMERCIAL				
NASA				
DOD				
TOTAL				288

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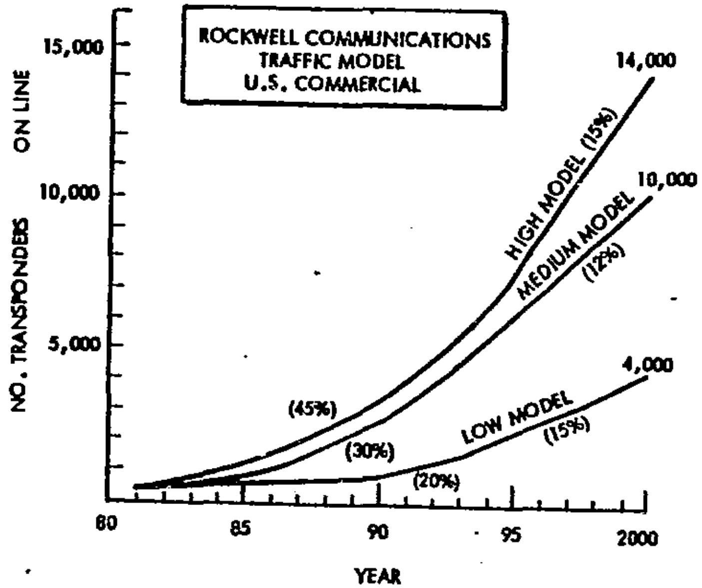
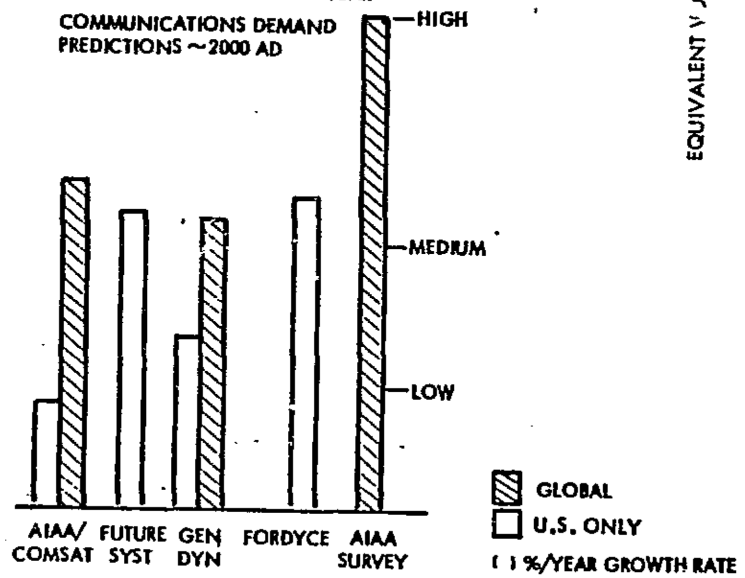
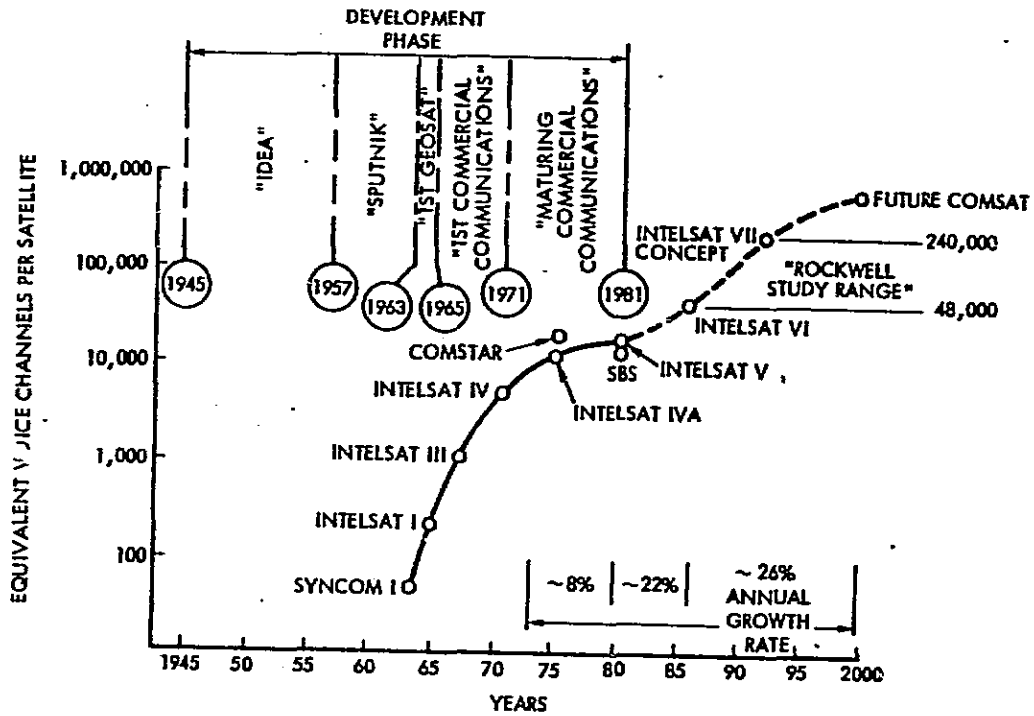
COMMUNICATION DEMAND PROJECTIONS AND TECHNOLOGY DEVELOPMENTS







NOTE: 1000 VOICE CHANNELS EQUIVALENT TO ONE 36 MHz TRANSPONDER

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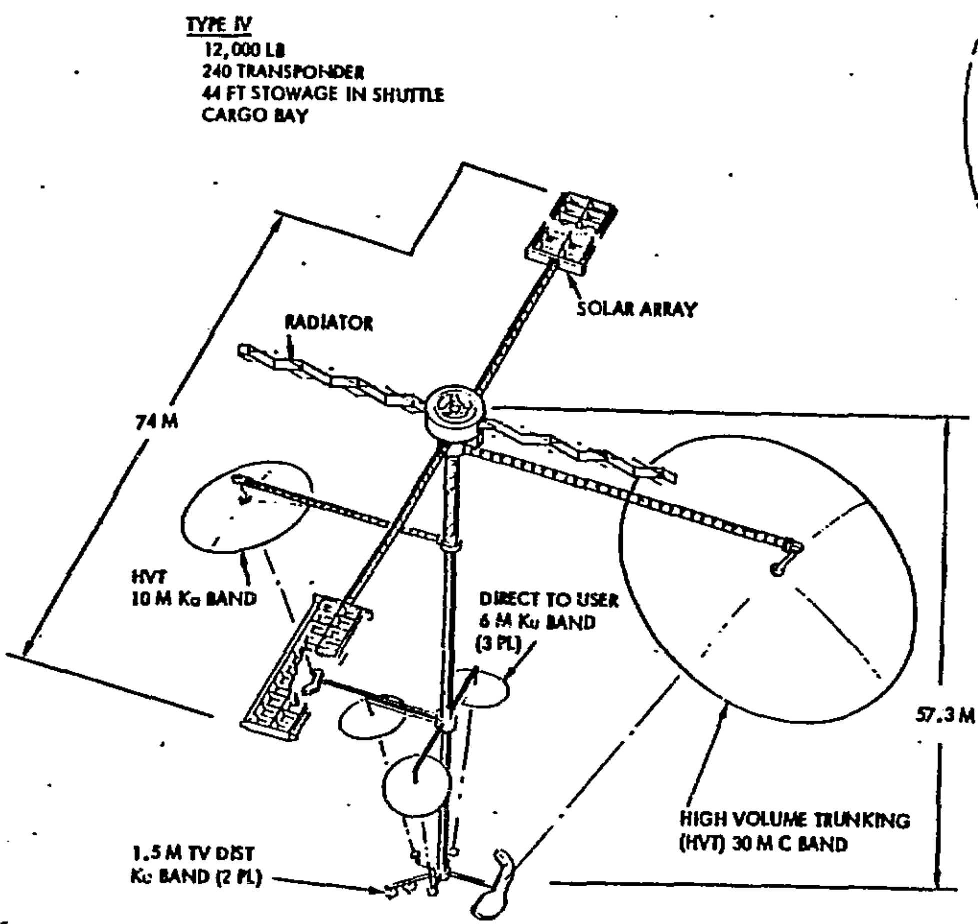
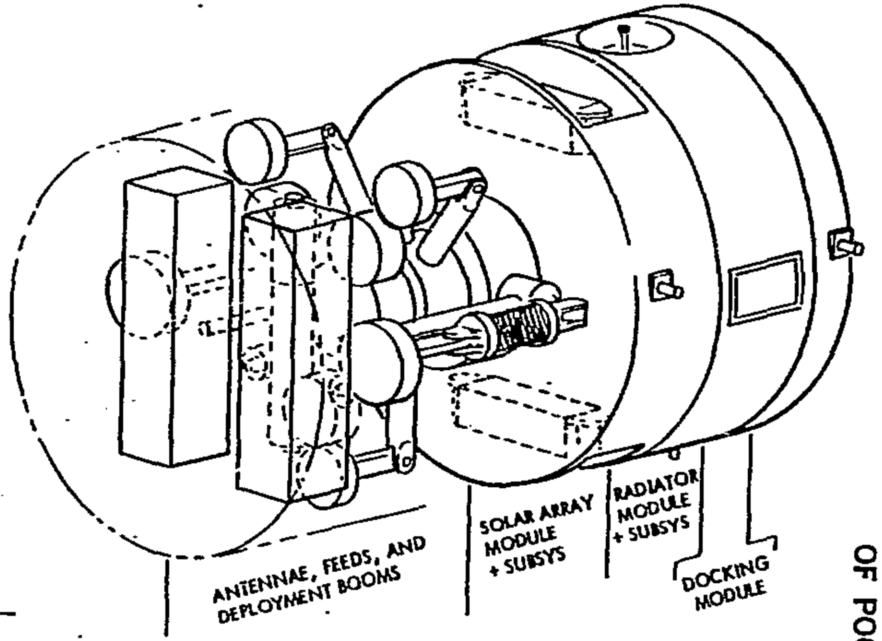
ADVANCED COMMUNICATIONS SATELLITE CONCEPT

12,000 LB GEO COMMSAT





STOWED CONFIGURATION

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MISSION MANIFEST DEVELOPMENT

PAYLOAD CATEGORY	MISS	OTV	MASS (LBS)	LENGTH (FEET)	SHUTTLE FLIGHT NO.	CARGO MANIFEST (CODE: WEIGHT (K LBS) / LENGTH (FT))
SOC						
SOC LOGISTICS	4	0	35,000	26	1 – 4	DM 4.5/7 · LOG MOD 35/26 · UNUSED 18/18 · ET 2.5/9
OTV						
OTV DELIVERY NO. 2	1	0	5,020	25	5	DM 4.5/7 · 5/25 · UNUSED 48/19 · ET 2.5/9
TELEOPERATOR	1	0	11,000	20	6	DM 4.5/7 · TELE 11/20 · UNUSED 42/24 · ET 2.5/9
COMMUNICATIONS						
US COMMERCIAL TYPE IV S/C	5	5	12,000	44	7 – 11	DM 4.5/7 · S/C 12/44 · ET 2.5/9
TYPE V S/C	1	1	12,000	26	12	DM 4.5/7 · S/C 12/26 · UNUSED 41/8 · ET 2.5/19
FOREIGN TYPE IV S/C	2	2	12,000	44		
TYPE V S/C	1	1				
DOD						

- 11 YEARS OPERATIONS
- ALL MISSIONS AREAS
- PAYLOAD PHYSICAL CHARACTERISTICS AND MANIFESTING GROUNDRULES USED TO ESTABLISH 3 TRAFFIC MODELS
- UNALLOCATED LOAD FACTOR (LF) AND PAYLOAD VOLUME USED IN PROPELLANT TRANSPORT ANALYSIS (A)

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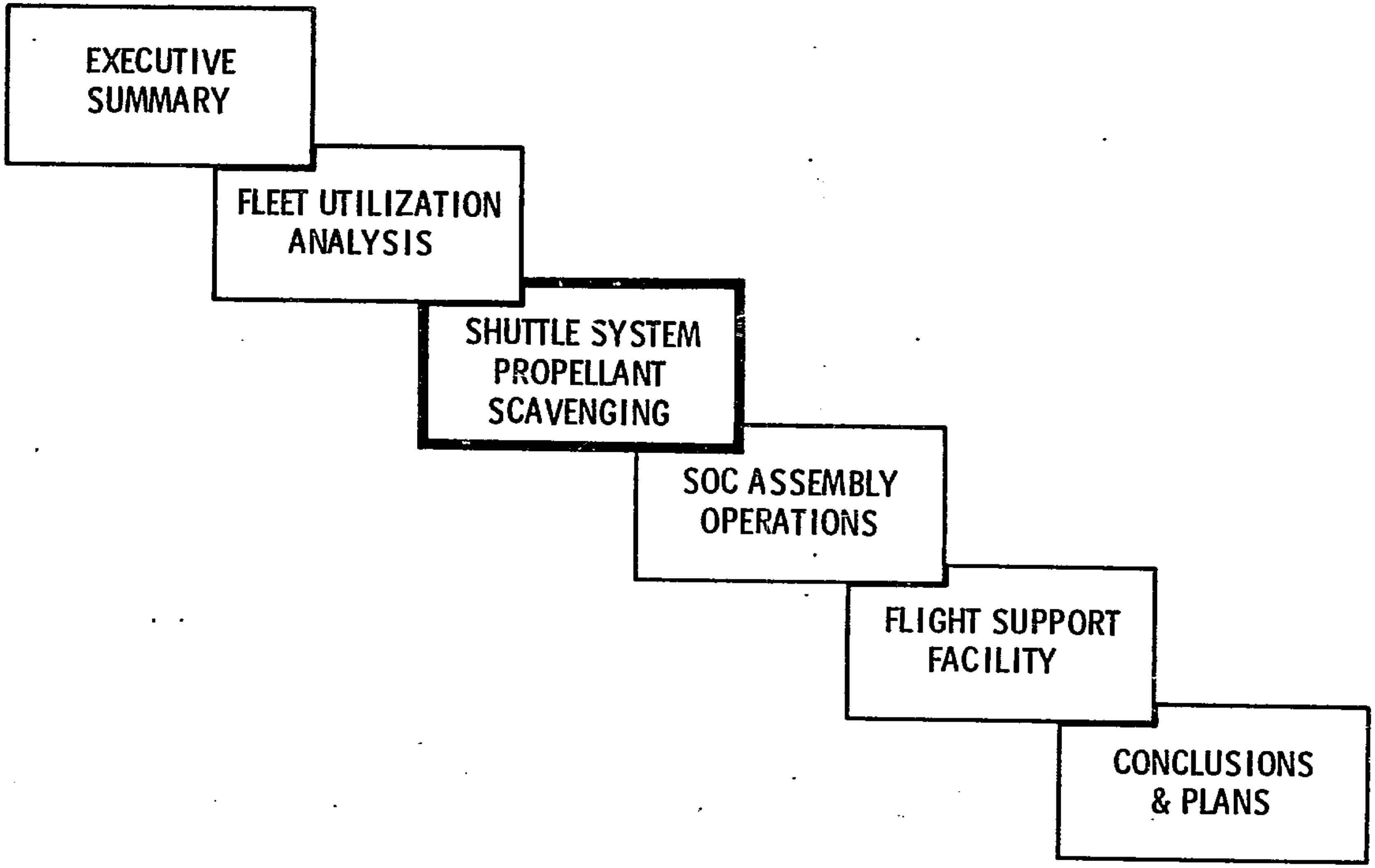
SUMMARY

GOALS:

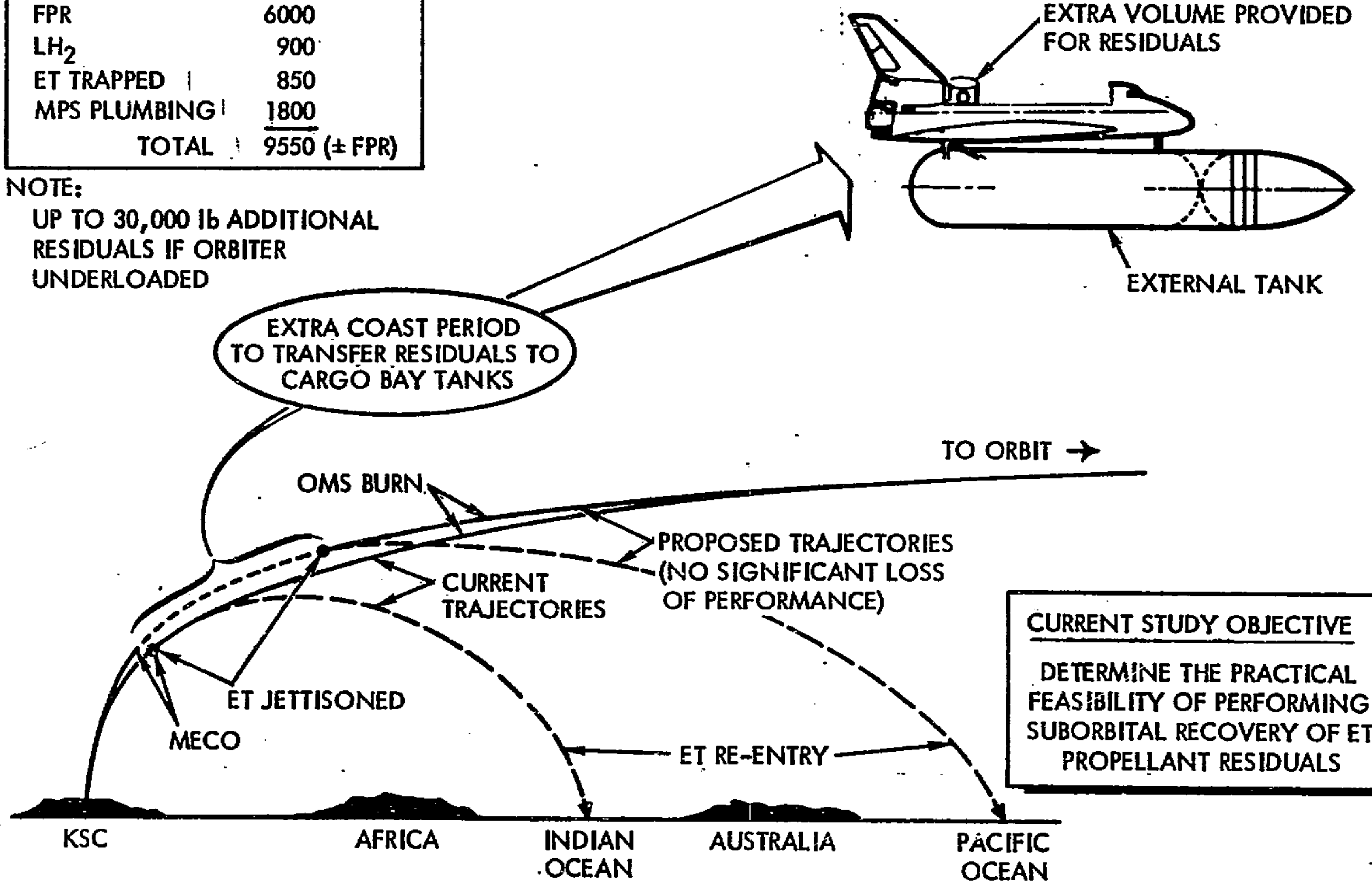
- DEVELOP AN UNDERSTANDING OF THE GROUND TURNAROUND PROCESS & POTENTIAL SOC RELATED INTERACTIONS
- DETERMINE THE SIGNIFICANCE &/OR NEED FOR DEDICATED ORBITER(S)
- SHOW FLEET IMPACTS FROM NON-SOC SCENARIO
- DETERMINE PROPELLANT TANK SIZES MATCHING TRAFFIC PREDICTIONS . . . , AND UNDERSTAND THE INTERACTIONS WITH PAYLOAD DENSITY, ET SCAVENGING AND PAYLOAD TOP OFF


EXECUTIVE SUMMARY
FLEET UTILIZATION ANALYSIS
SHUTTLE SYSTEM PROPELLANT SCAVENGING
SOC ASSEMBLY OPERATIONS
FLIGHT SUPPORT FACILITY
CONCLUSIONS & PLANS

ET RESIDUALS RECOVERY CONCEPT

AVAILABLE RESIDUALS - lb	
FPR	6000
LH_2	900
ET TRAPPED	850
MPS PLUMBING	1800
TOTAL	9550 (± FPR)

NOTE:
UP TO 30,000 lb ADDITIONAL RESIDUALS IF ORBITER UNDERLOADED

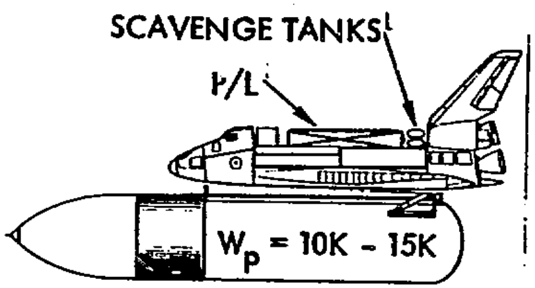


CURRENT STUDY OBJECTIVE

DETERMINE THE PRACTICAL FEASIBILITY OF PERFORMING SUBORBITAL RECOVERY OF ET PROPELLANT RESIDUALS

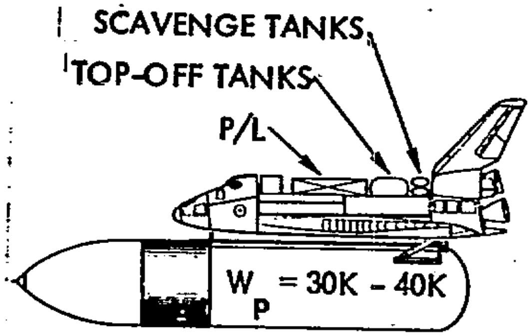
POSSIBLE SCAVENGING SCENARIOS

BASIC SCAVENGING



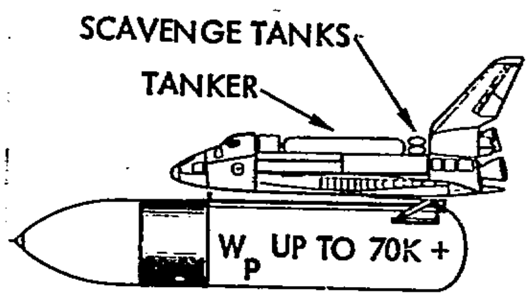
- LAUNCH WITH 65K P/L
- RECOVER STATISTICAL FPR
- SIZE SCAVENGE SYSTEM TO +3σ RESIDUALS
- OPTIONS CAN BE SIZED TO OTHER P/L WEIGHTS

P/L TOP-OFF



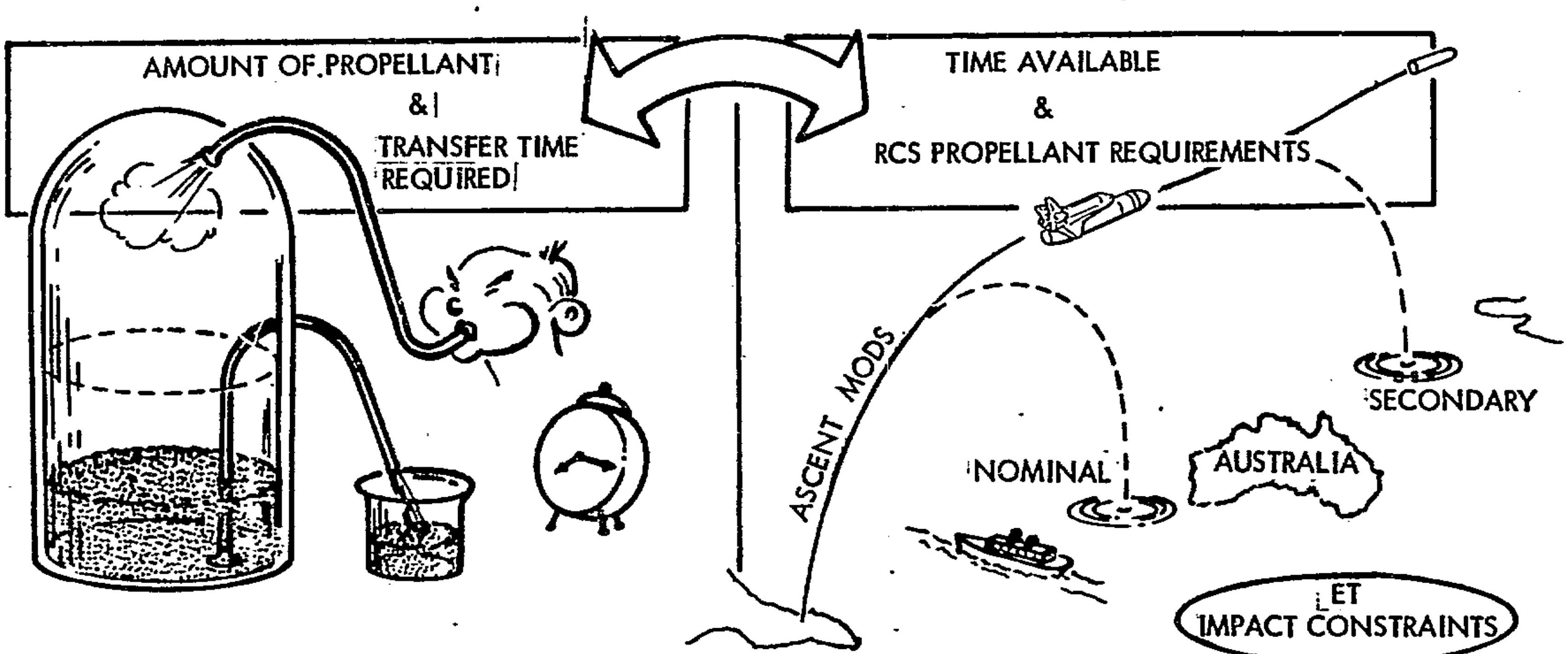
- LAUNCH WITH LESS THAN 65K HARD CARGO
- TOP-OFF TO 65K WITH PROPELLANT
- SIZE SCAVENGE SYSTEM TO +3σ RESIDUALS
- OPTION TO COMBINE SCAVENGE VOLUME INTO TOP-OFF TANKS
- OPTION TO LAUNCH "DRY"

DEDICATED TANKER



- LAUNCH WITH 65K PROPELLANT
- SIZE SCAVENGE SYSTEM TO +3σ RESIDUALS
- OPTION TO OVERSIZE TANKER TO INCLUDE SCAVENGE
- OPTION TO LAUNCH "DRY"

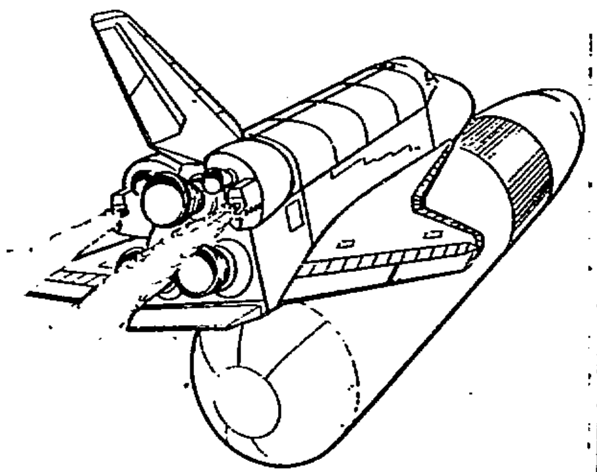
KEY ISSUES



- MECO TRANSIENTS
- ULLAGE THRUST STEERING
- PRACTICAL HARDWARE CONCEPTS
- PROCEDURES AND CREW OPERATIONS
- SAFETY IMPLICATIONS

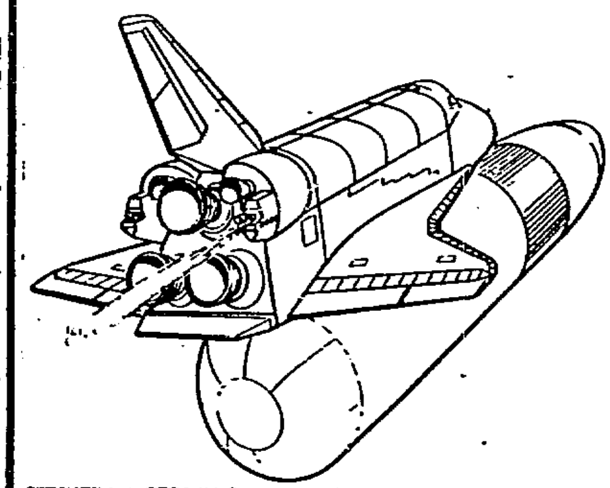
ULLAGE THRUST OPTIONS

DUAL PRCS THRUSTERS



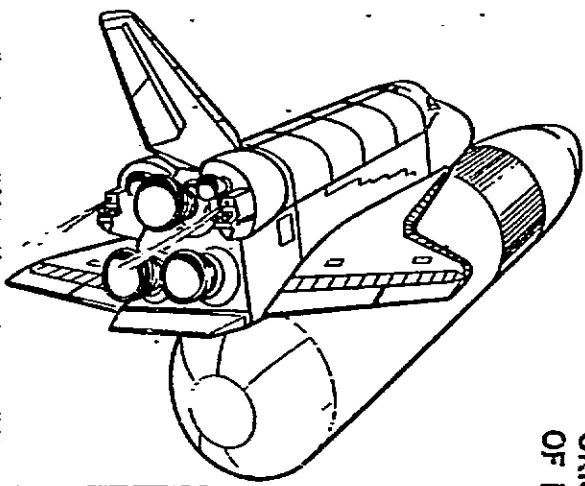
- $2 \times 870 = 1740\ lb_f$
- $T/W = 0.0047$ g's
- $\dot{w}_p \approx 414$ lb/min
- MINIMUM ORBITER IMPACT

SINGLE PRCS THRUSTER



- $1 \times 870 = 870\ lb_f$
- $T/W = 0.0024$ g's
- $\dot{w}_p \approx 207$ lb/min
- ATTITUDE CONTROL SOFTWARE MOD

ADDED VERNIER THRUSTERS



- $T_{INITIAL} = 2 \times 870 = 1740\ lb_f$ (APPROX. 40 - 60 sec)
- T_{FINAL} = DRAG + 50 lb_f
- $T/W \approx 10^{-4}$ g's
- $\dot{w}_p \approx 11.5$ lb/min
- HARDWARE & SOFTWARE MODS

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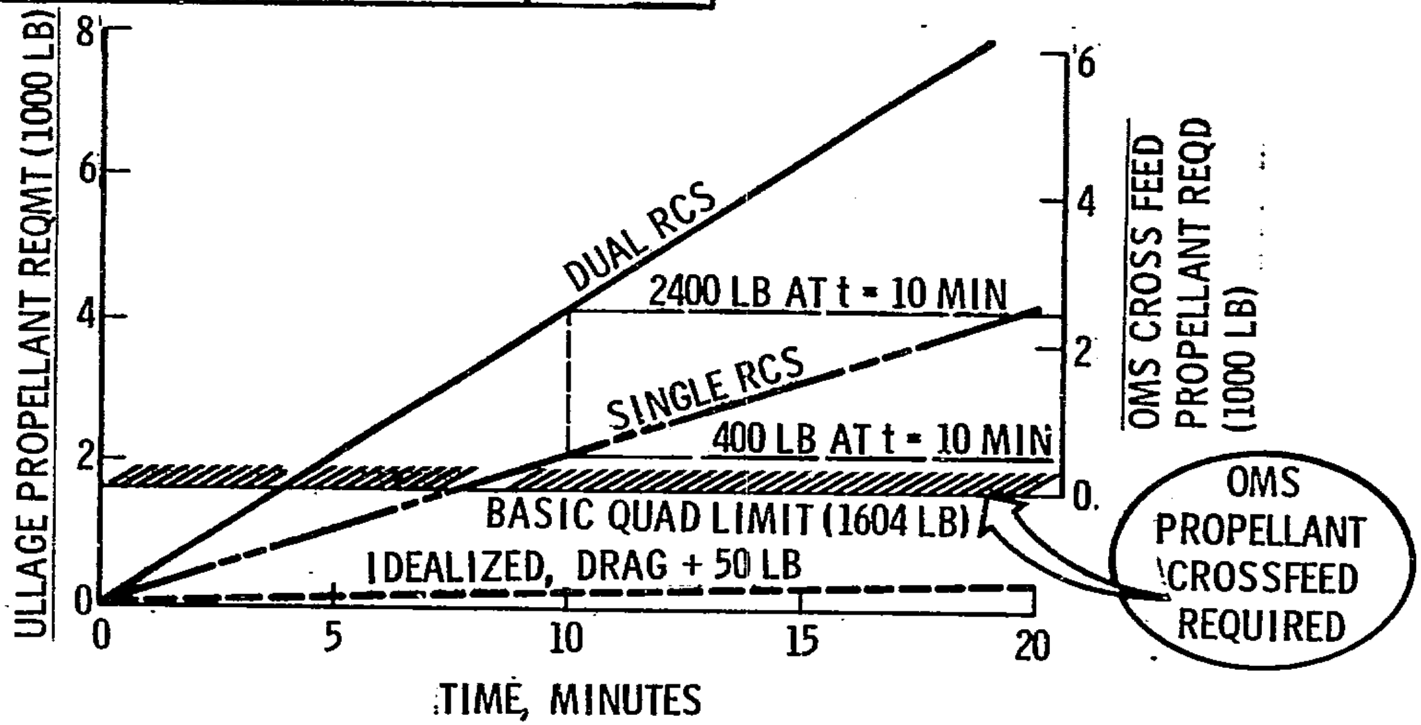
ULLAGE THRUST PROPELLANT REQUIREMENTS

RCS PROPELLANT BUDGET, LB	
ASCENT/DESCENT	(3398)
INSERTION AND ORBIT ADJUST	1127
ENTRY	1164
RESIDUALS AND CONTINGENCIES	1107
MISSION OPERATIONS	(1450)
RENDEZVOUS	1450
TOTAL	4848

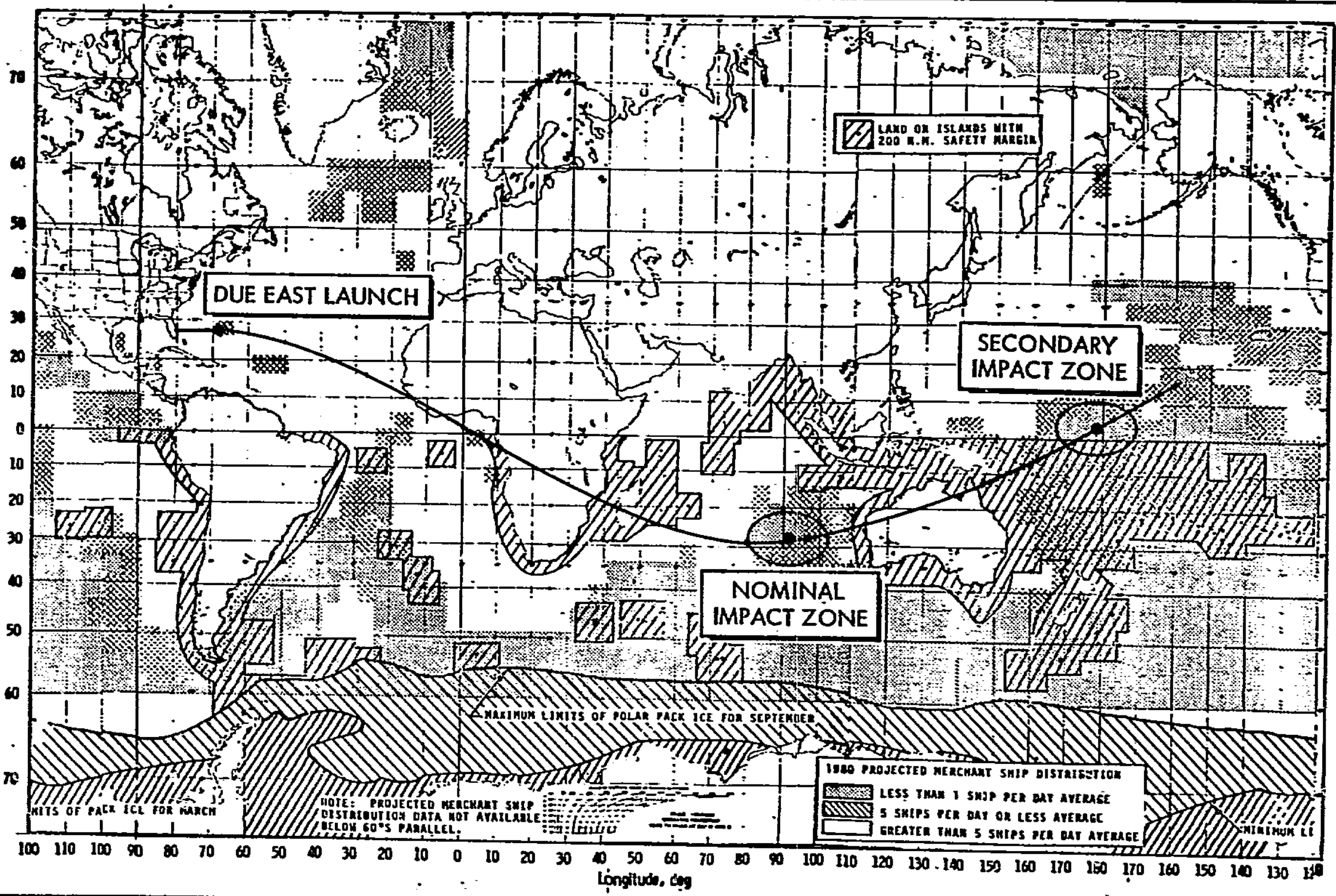
TOTAL PROPELLANT LOADED
7254 LB

AVAILABLE FOR ULLAGE THRUST
7254-4848 = 2406 LB

2/3 IN AFT QUADS = 1604 LB



ET IMPACT CONSTRAINTS



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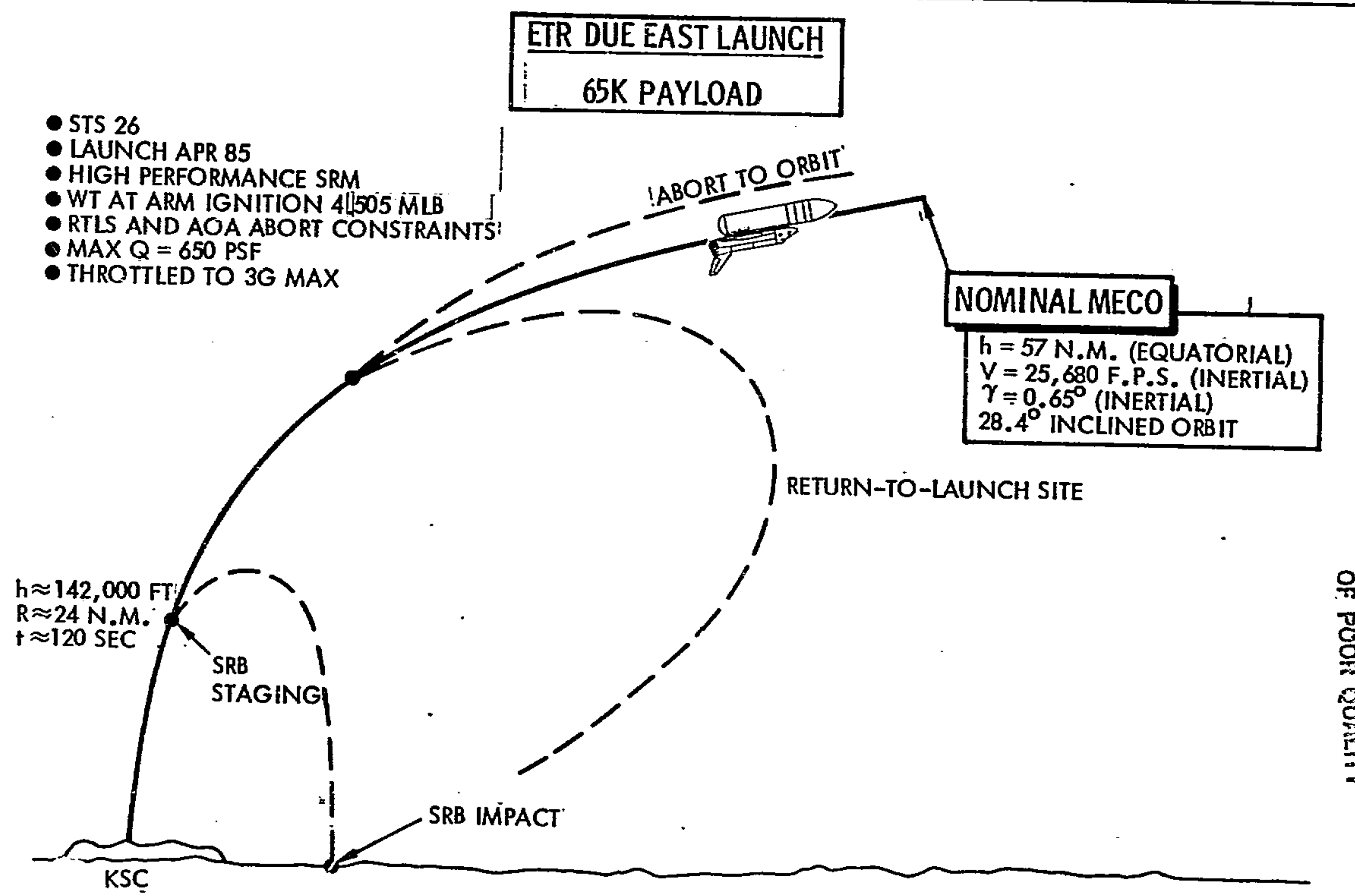
REFERENCE ASCENT PROFILE



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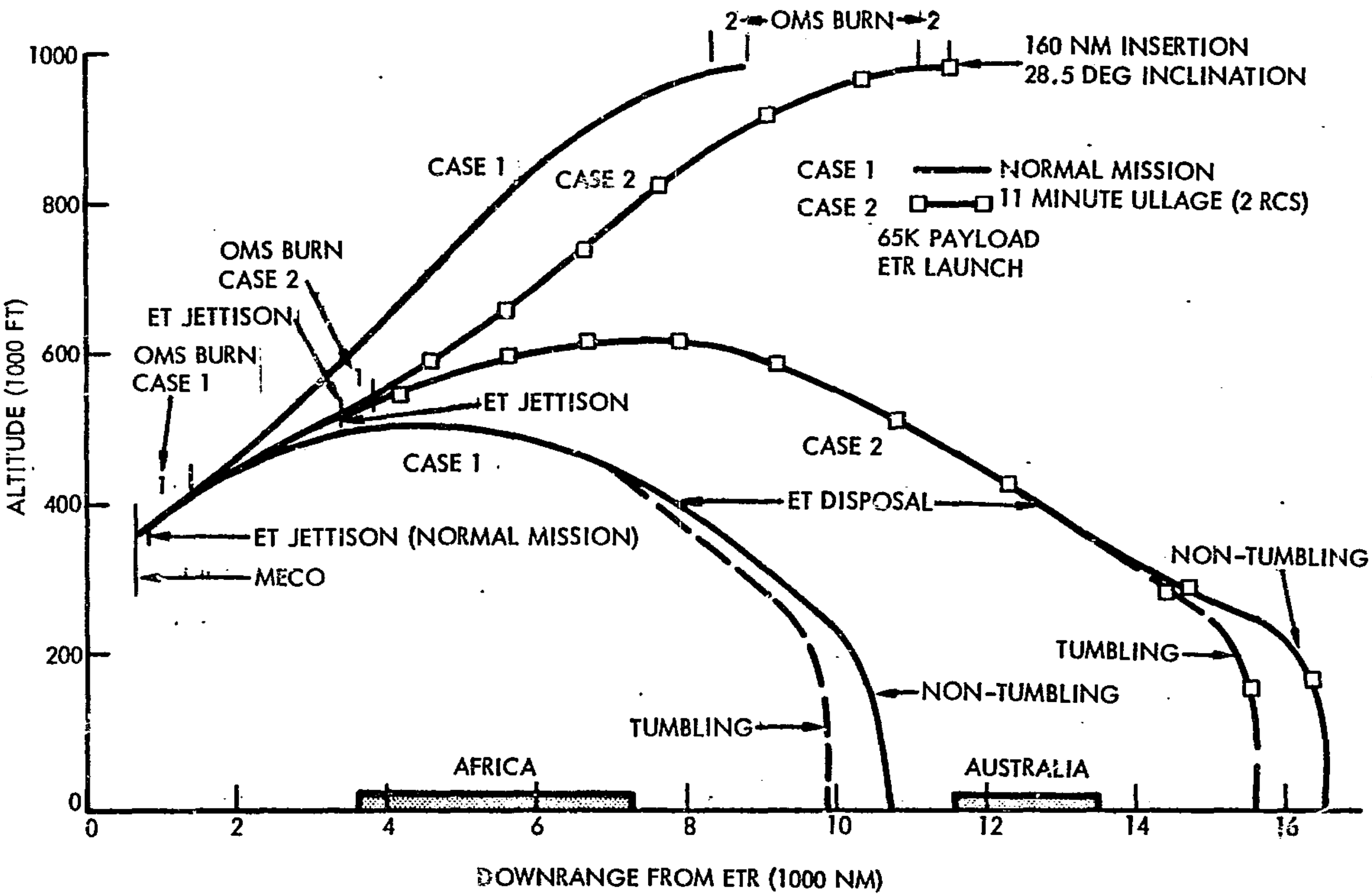
POST MECO TRAJECTORY PROFILE



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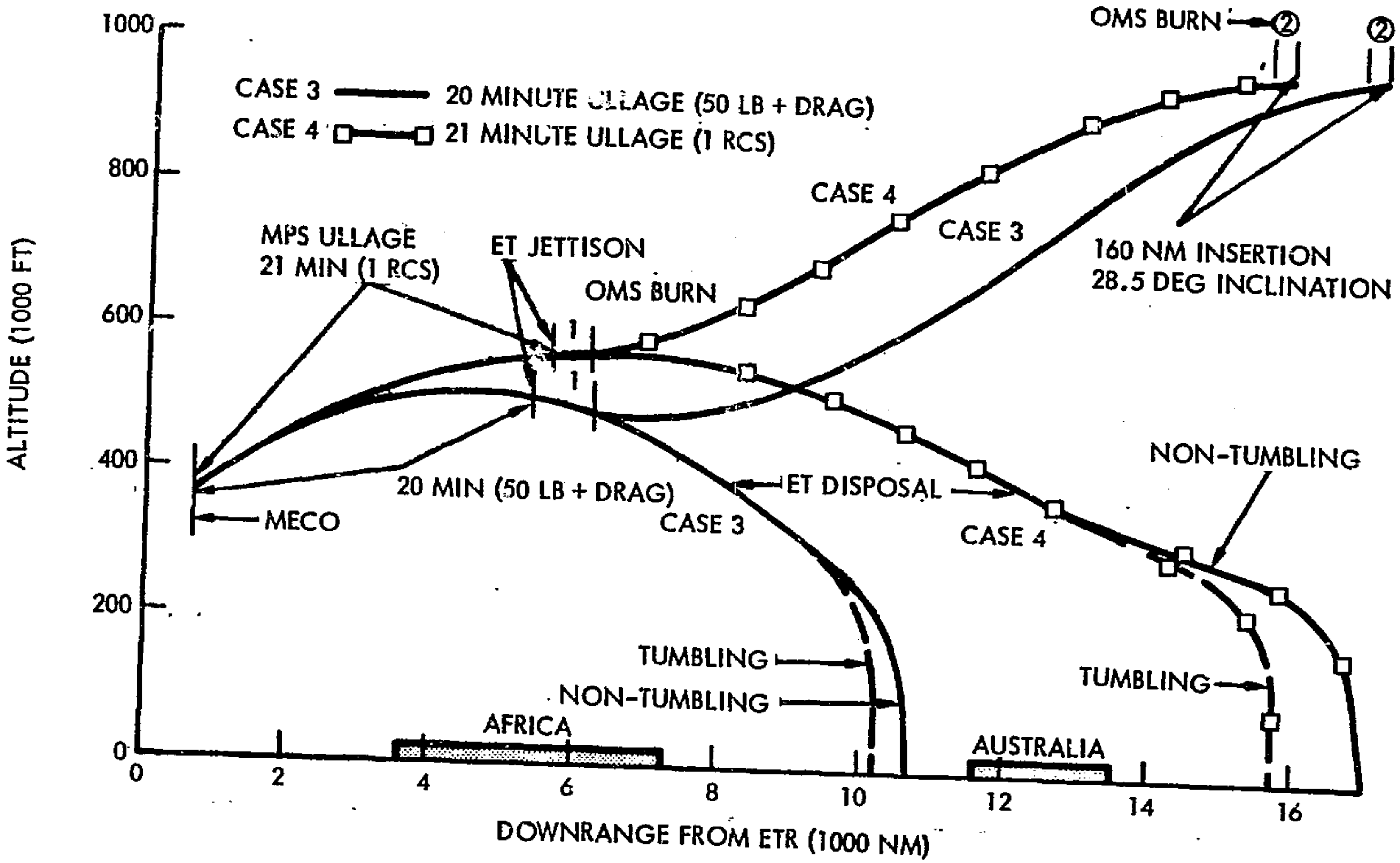
POST MECO TRAJECTORY PROFILE OPTIONS



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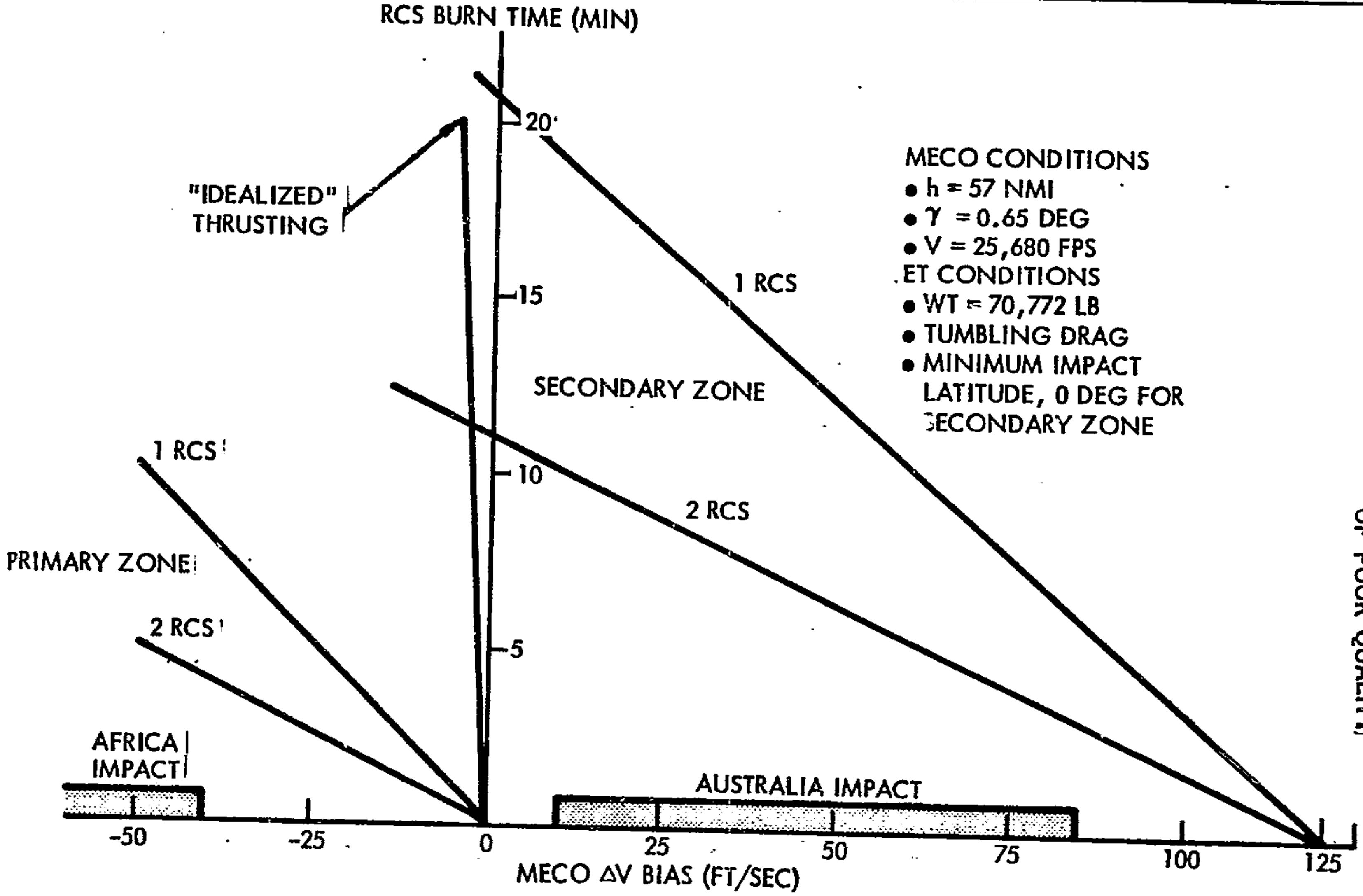
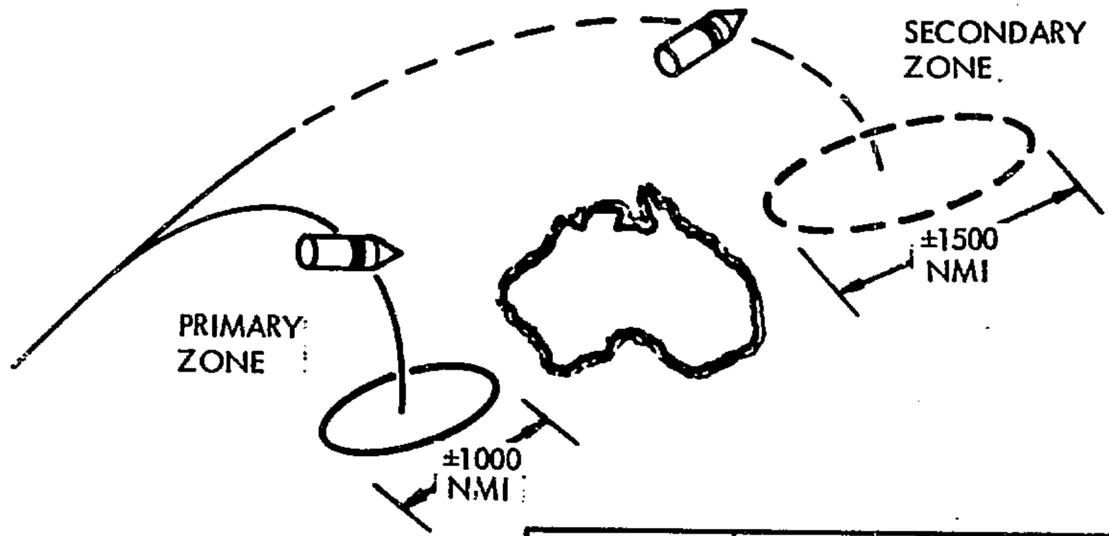
DELTA MECO FOR ET IMPACT CONTROL



ET IMPACT DISPERSIONS



SECONDARY ZONE DISPERSIONS ARE PROBABLY ACCEPTABLE

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IMPACT ZONE	NUMBER OF RCS	RCS THRUST (LB)	THRUST TIME (MINUTES)	$\partial R/\partial W$ (NM/%)	$\partial R/\partial C_A$ (NM/%)	$\partial R/\partial V$ (NM/FPS)	$\partial R/\partial \rho$ (NM/%)
SECONDARY	1	870	20.8	10	−9.8	109	−10.1
SECONDARY	2	1740	11.0	6.4	−5.9	63	−6.1
PRIMARY	1	870	5.0	2.8	−2.9	42	−3.0
PRIMARY	2	1740	5.0	2.8	−3.0	43	−3.1

V_{MECO} = 25,680 FPS (NOMINAL)

ET WEIGHT = 70,772 LB

CA_{ET} = 0.25

STD AMOS (1962)

PAYLOAD IMPACTS

OPTION	ET IMPACT ZONE	NO. OF RCS THRUSTERS	THRUST (LB)	ULLAGE TIME (MINUTES)	ΔV MECO (FPS)	ΔV P/L (1) PER ΔMECO (LB)	ΔOMS PROPELLANT (LB)	RCS PROPELLANT FOR ULLAGE THRUST (LB)		ΔP/L NET (LB)
								TOTAL	CROSSFEED	
1	I	2	1740	5	-50	+1284	+474	2070	466	+ 344
2	I	1	870	5	-25	+ 642	+ 469	1035	- 569 (2)	+742
3	I	0	50+DRAG	20	-5	+128	+ 260	224	- 1380 (2)	+1248
4	II	1	870	20.3	0	0	- 2597	4306	2702	- 105
5	II	2	1740	11	0	0	-2564	4554	2950	- 386
6	II	2	1740	8	+30	-771	-2589	3312	1708	+110

(1) AN EARLY MECO CUTOFF PROVIDES AN INCREASE IN PAYLOAD AT THE RATE OF 25.7 LB PER FPS

(2) NEGATIVE NUMBER INDICATES LESS THAN FULL RCS PROPELLANT IS REQUIRED AND OFFLOADED PROPELLANT COULD BE CREDITED TO ADDITIONAL PAYLOAD.

NEGLIGIBLE PAYLOAD IMPACT

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THRUST AND CG GEOMETRY

AFT RCS THRUST APPLICATION

	X_o	Y_o	Z_o
LEFT SIDE UP	1516 1529 1542	-132 -132 -132	480.5 480.5 480.5
RIGHT SIDE UP	1516 1529 1542	132 132 132	480.5 490.5 480.5

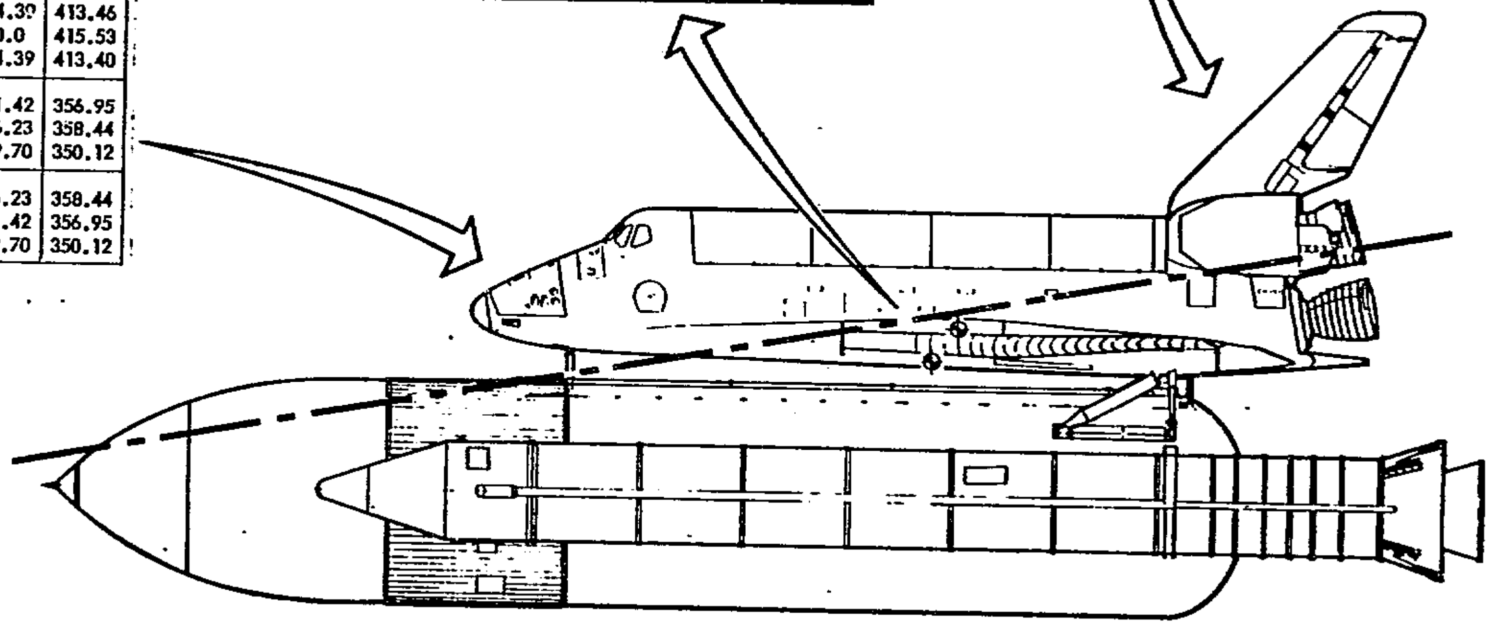
	X_o	Y_o	Z_o
RIGHT SIDE DOWN	1516 1529 1542	111.95 111.0 110.06	437.4 440.0 442.6
LEFT SIDE DOWN	1516 1529 1542	-111.95 -111.0 -110.06	437.4 440.0 442.6

CG COORDINATES

BRM NO. 6	MECO MASS, lb	X_o	Y_o	Z_o
65K ETR	366,500	964	2.1	324
30K ETR	352,400	922	2.0	266

FWD RCS THRUST APPLICATION

	X_o	Y_o	Z_o
THRUST PLUME UP	350.93 350.92 350.93	14.39 0.0 -14.39	413.46 415.53 413.40
LEFT SIDE DOWN	333.84 348.44 324.35	-61.42 -66.23 -59.70	356.95 358.44 350.12
RIGHT SIDE DOWN	348.44 333.84 324.35	66.23 61.42 59.70	358.44 356.95 350.12



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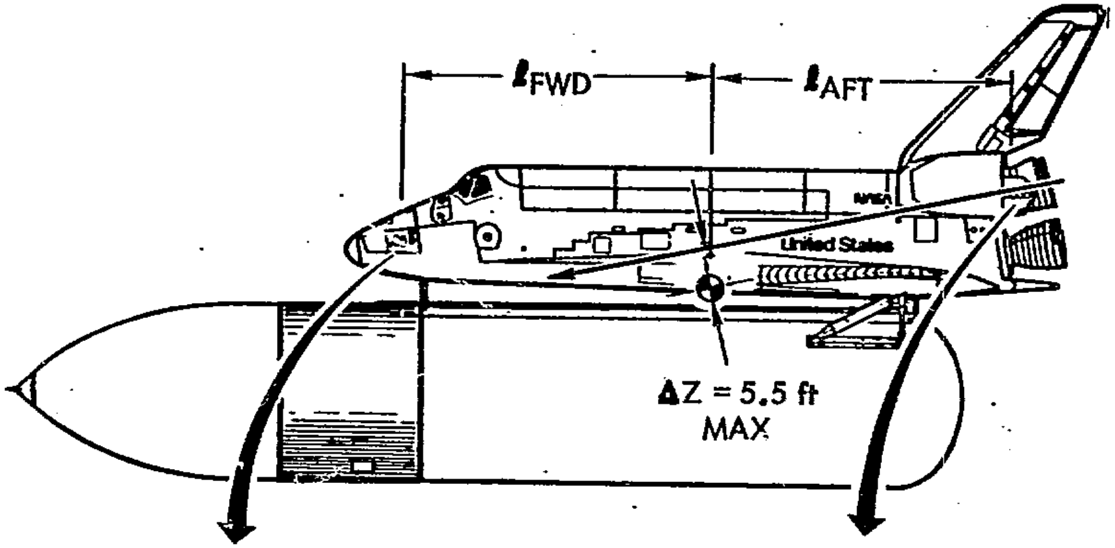
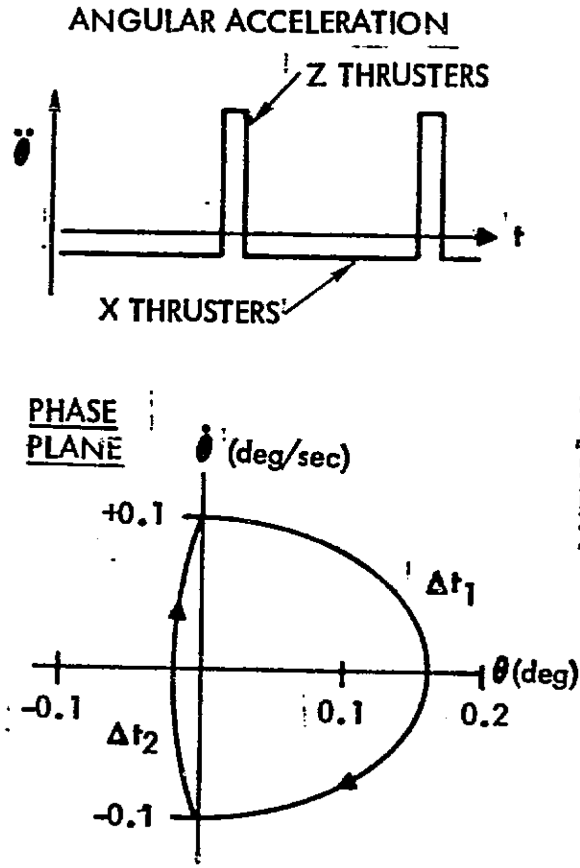
ULLAGE THRUST STEERING





FWD RCS STEERING

$T_Z = 640\ lb_f$

$$\%\ T_Z = \frac{\Delta Z}{\ell_{FWD}} \times \frac{870}{640}$$

$\approx 2.7\%$ PER ft ΔZ

$\dot{w}_{P_{MAX}} = 428$ lb/min

AFT RCS STEERING

$T_Z = 870\ lb_f$

$$\%\ T_Z = \frac{\Delta Z}{\ell_{AFT}}$$

$\approx 2\%$ PER ft ΔZ

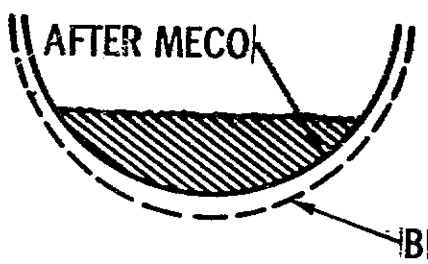
$\dot{w}_{P_{MAX}} = 414$ lb/min

$\Delta t_1 \approx 6.6$ sec

$\Delta t_2 \approx 0.8$ sec

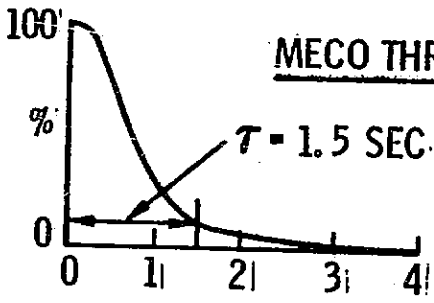
MECO THRUST TRANSIENT EFFECTS

BULKHEAD "TWANG"



BULKHEAD STRAIN ENERGY

MECO THRUST TAILOFF

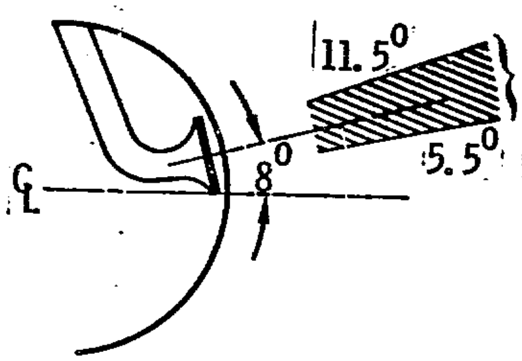


- SHUTTLE HYDRO ELASTIC MODELING AT MECO SHELL-FLUID $f_c = 26$ Hz
- $\frac{\tau}{T} = 39$
- STRUCTURAL RESPONSE

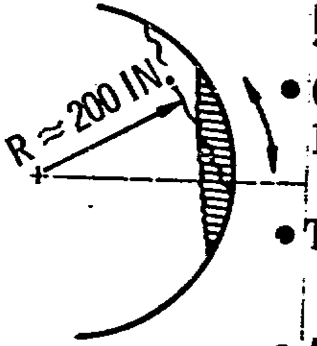
$$R = 1 + \left| \frac{\cos \frac{\pi \tau}{T}}{\left(2 \frac{\tau}{T}\right)^2 - 1} \right| = 1.00016$$

NO "TWANG" PROBLEM ✓

RCS THRUST DIRECTION



MAIN ENGINE THRUST ENVELOPE AT MECO (DUE TO CG VARIATIONS)



PENDULUM MOTION

- CENTERED ABOUT 10^0 RCS THRUST DIRECTION
- $T = 2\pi \sqrt{\frac{\ell}{g}} = 64.8$ SEC AT T/W = 0.0047 g's
- AMPLITUDE $R\,\theta_{MAX} \approx 16$ INCHES

VERY MILD TRANSIENT ✓

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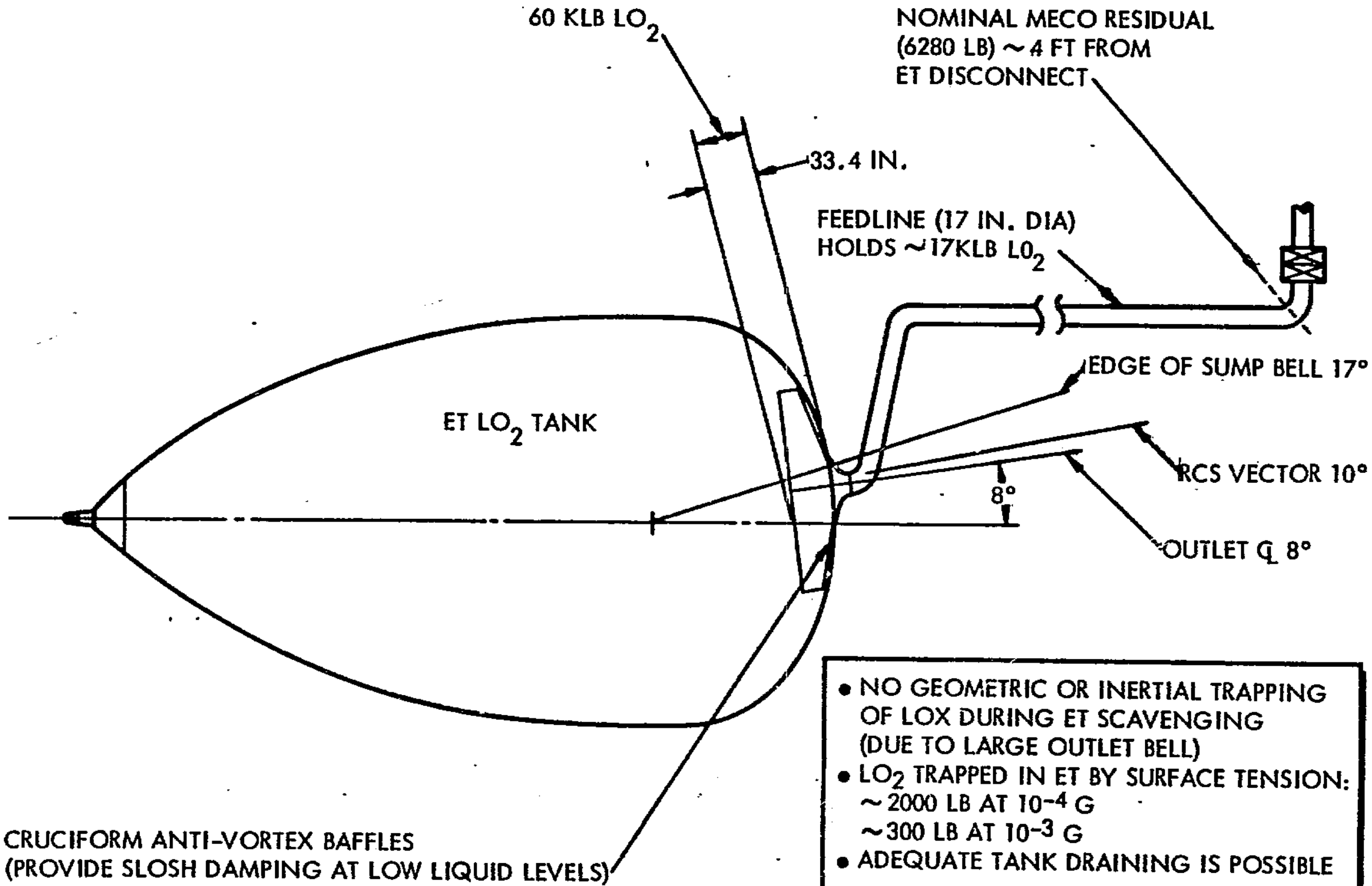
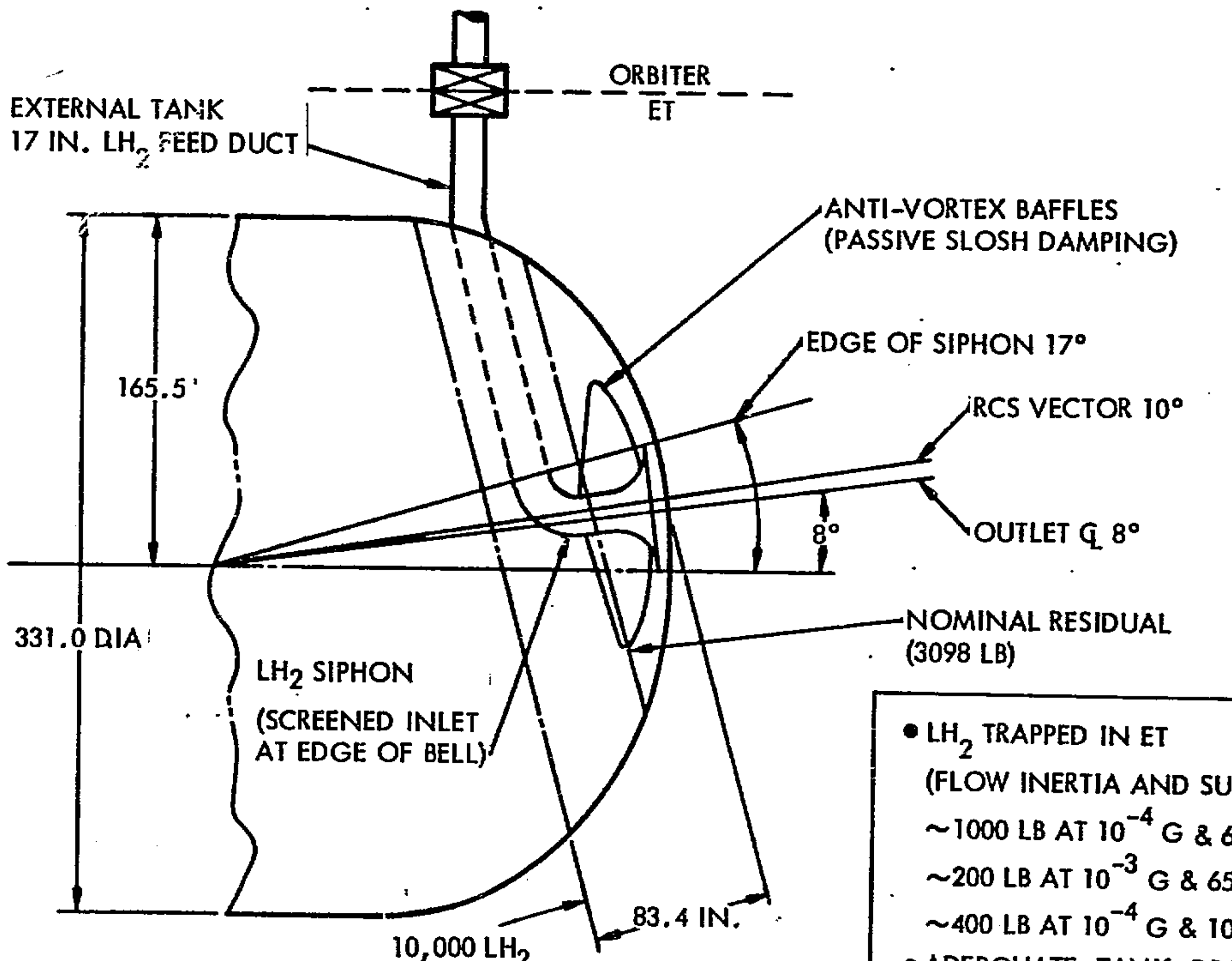
ET LO_2 TANK DRAINING



- NO GEOMETRIC OR INERTIAL TRAPPING OF LOX DURING ET SCAVENGING (DUE TO LARGE OUTLET BELL)
- LO_2 TRAPPED IN ET BY SURFACE TENSION:
  ~2000 LB AT 10^{-4} G
  ~300 LB AT 10^{-3} G
- ADEQUATE TANK DRAINING IS POSSIBLE

LH_2 TANK DRAINING



- LH_2 TRAPPED IN ET
  (FLOW INERTIA AND SURFACE TENSION)
  $\sim$1000 LB AT 10^{-4} G & 650 LB/MIN
  $\sim$200 LB AT 10^{-3} G & 650 LB/MIN
  $\sim$400 LB AT 10^{-4} G & 100 LB/MIN
- ADERQUATE TANK DRAINING IS POSSIBLE

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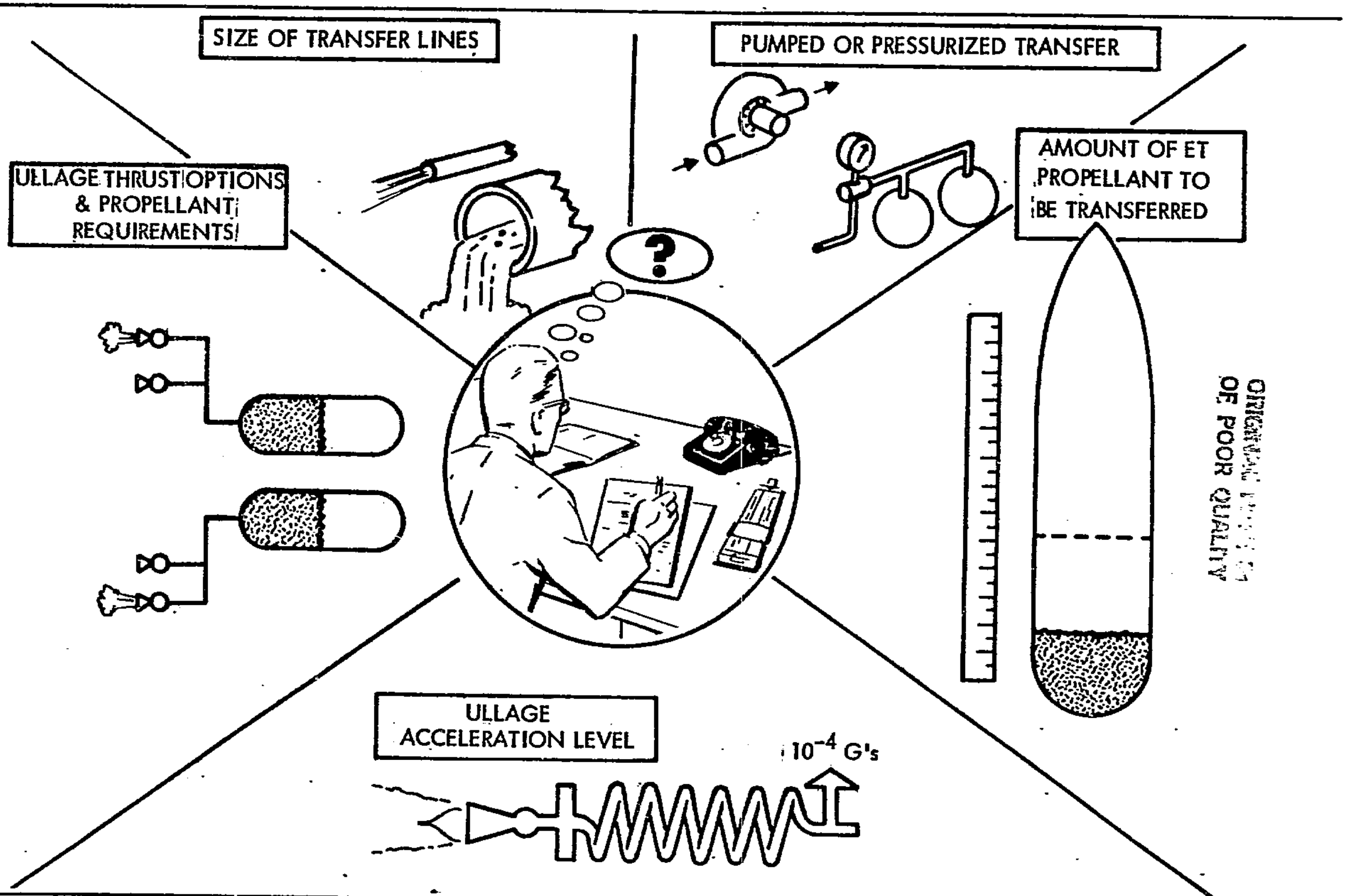
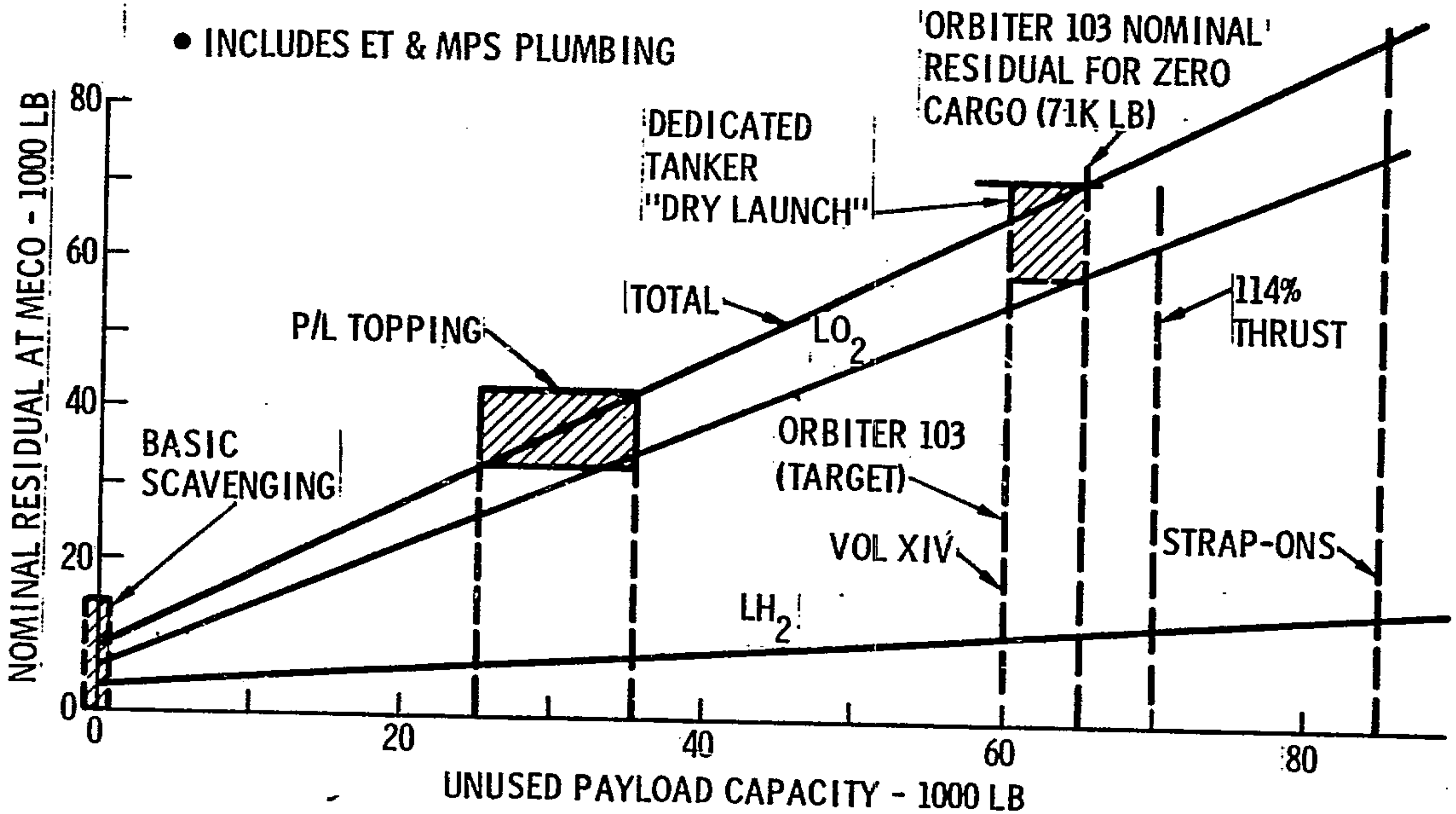
MAIN PROBLEM VARIABLES



NOMINAL PROPELLANT RESIDUALS AT MECO



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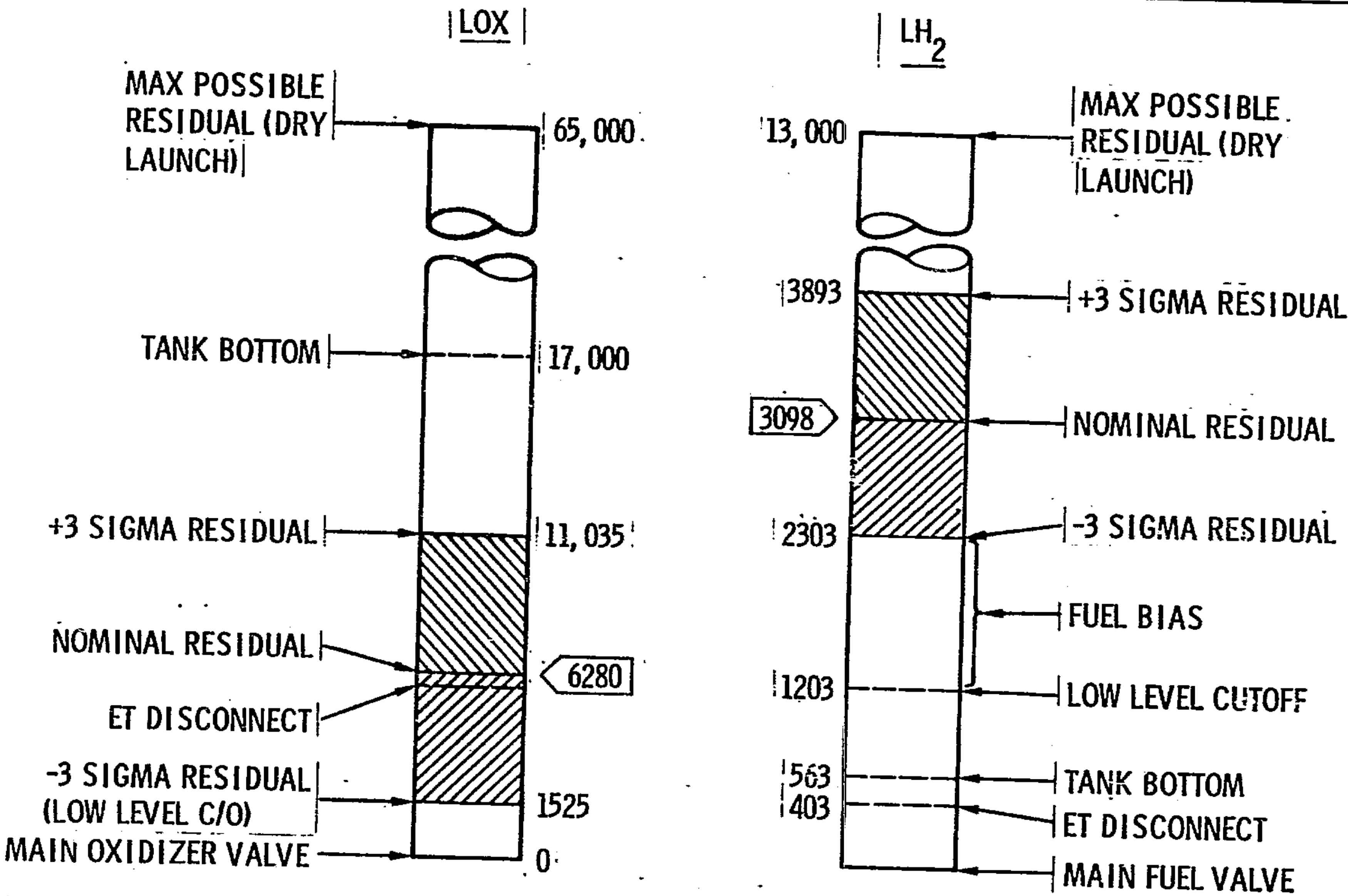
PROPELLANT RESIDUALS AT MECO (+5 SECONDS)



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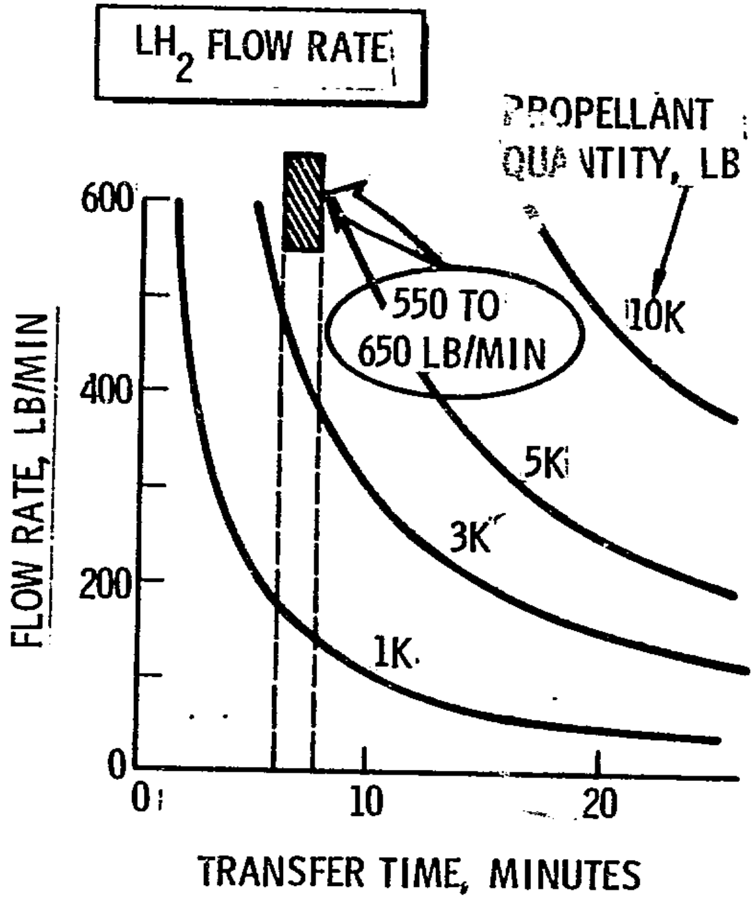
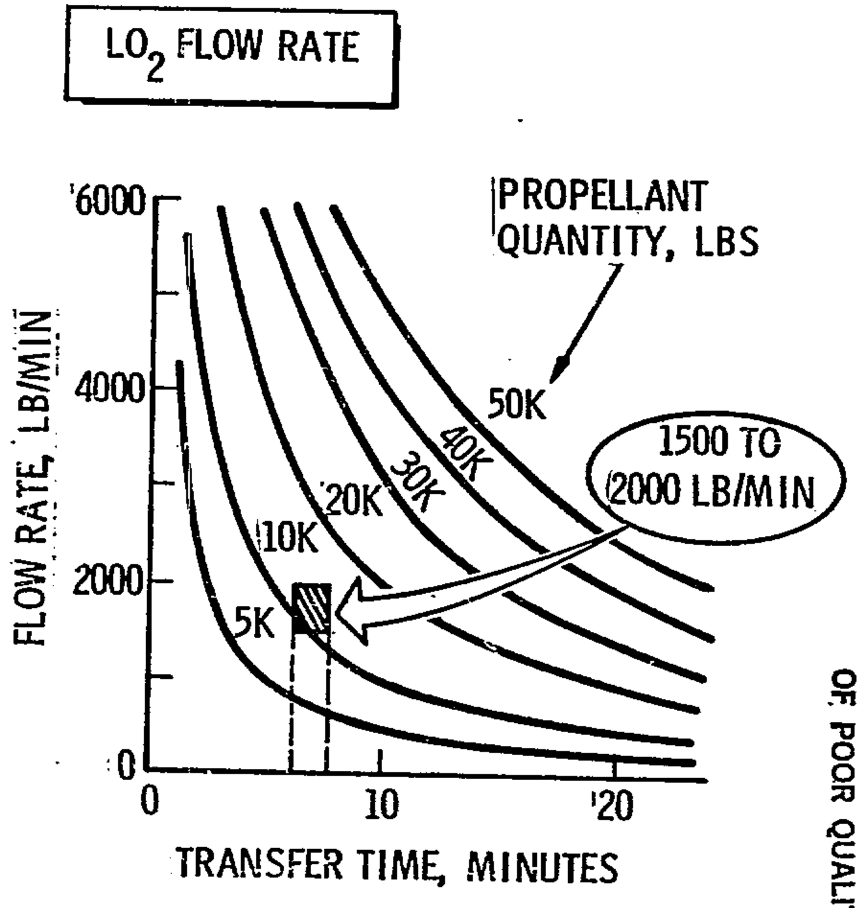
FLOW RATE REQUIREMENTS





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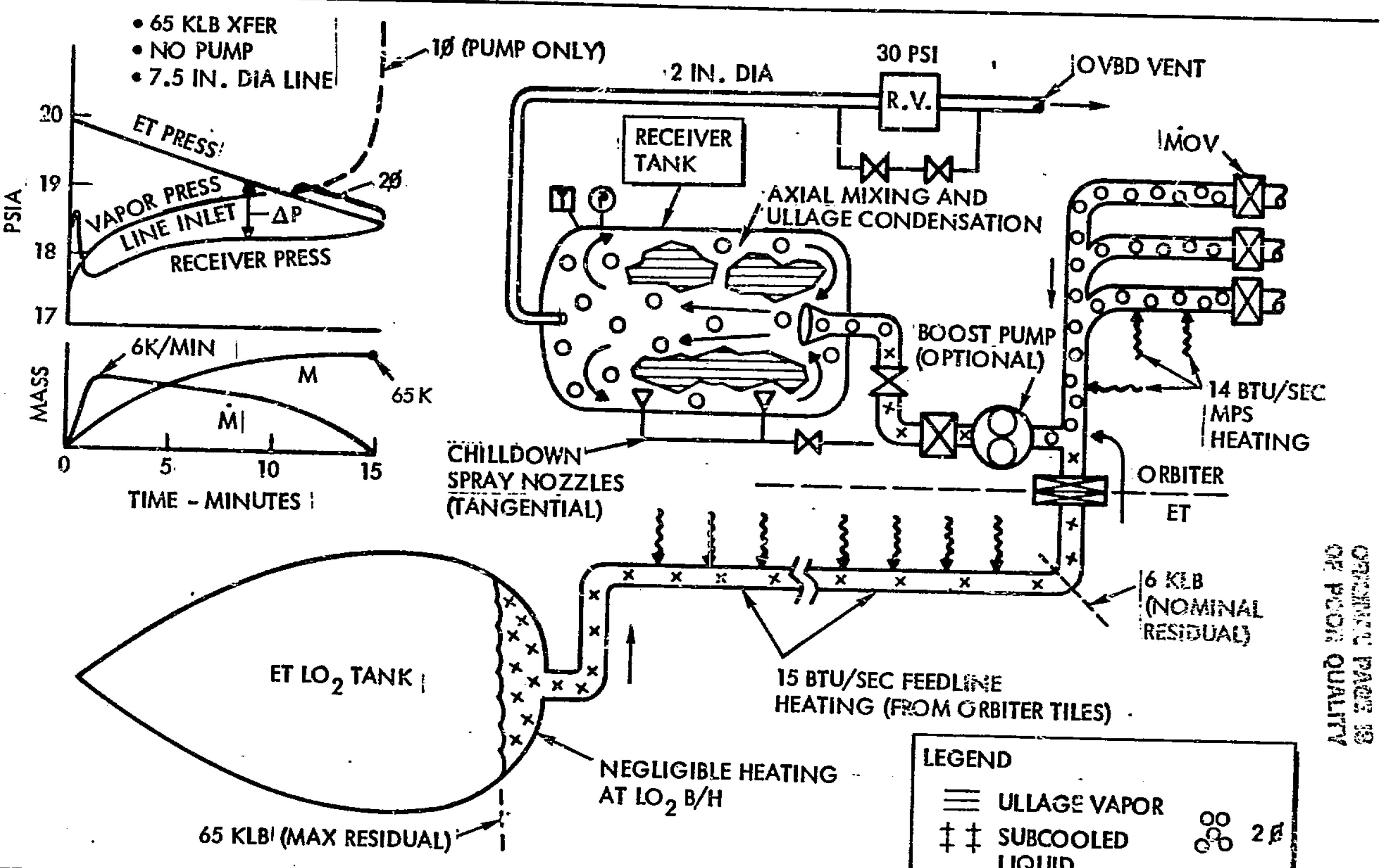
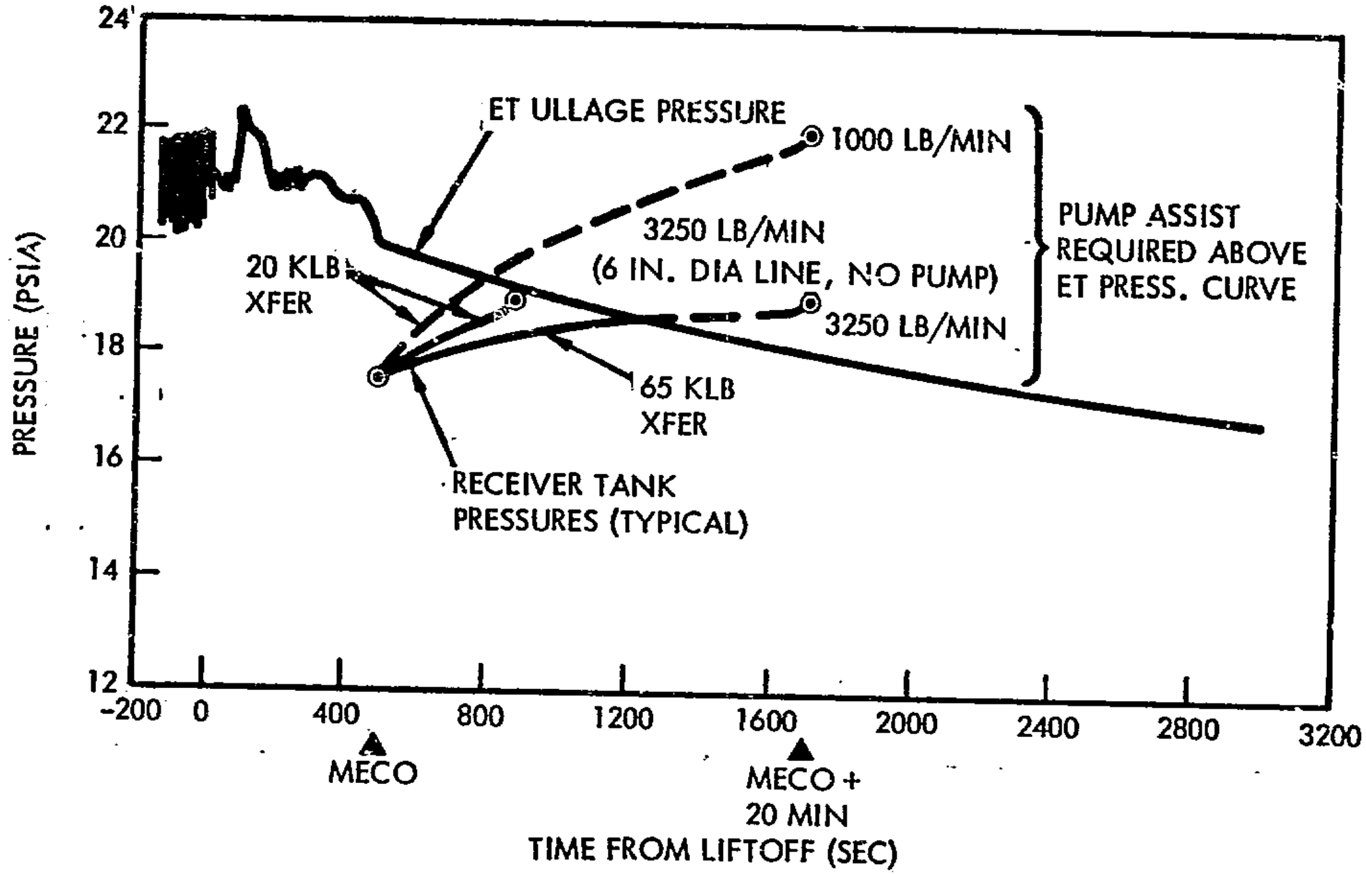
ET LO_2 TRANSFER PHENOMENA



LO_2 TRANSFER PRESSURE HISTORIES

- 98% RESIDUAL RECOVERY
- COMPUTER SIMULATION OF ET ULLAGE PRESSURE HISTORY
- POST-MECO ET ACCELERATION 10^{-4} G

LO_2 PRESSURIZATION SYSTEM PERFORMANCE FOR BRM-1
FCV ORIFICES -6500, -6510
VARIABLE CO



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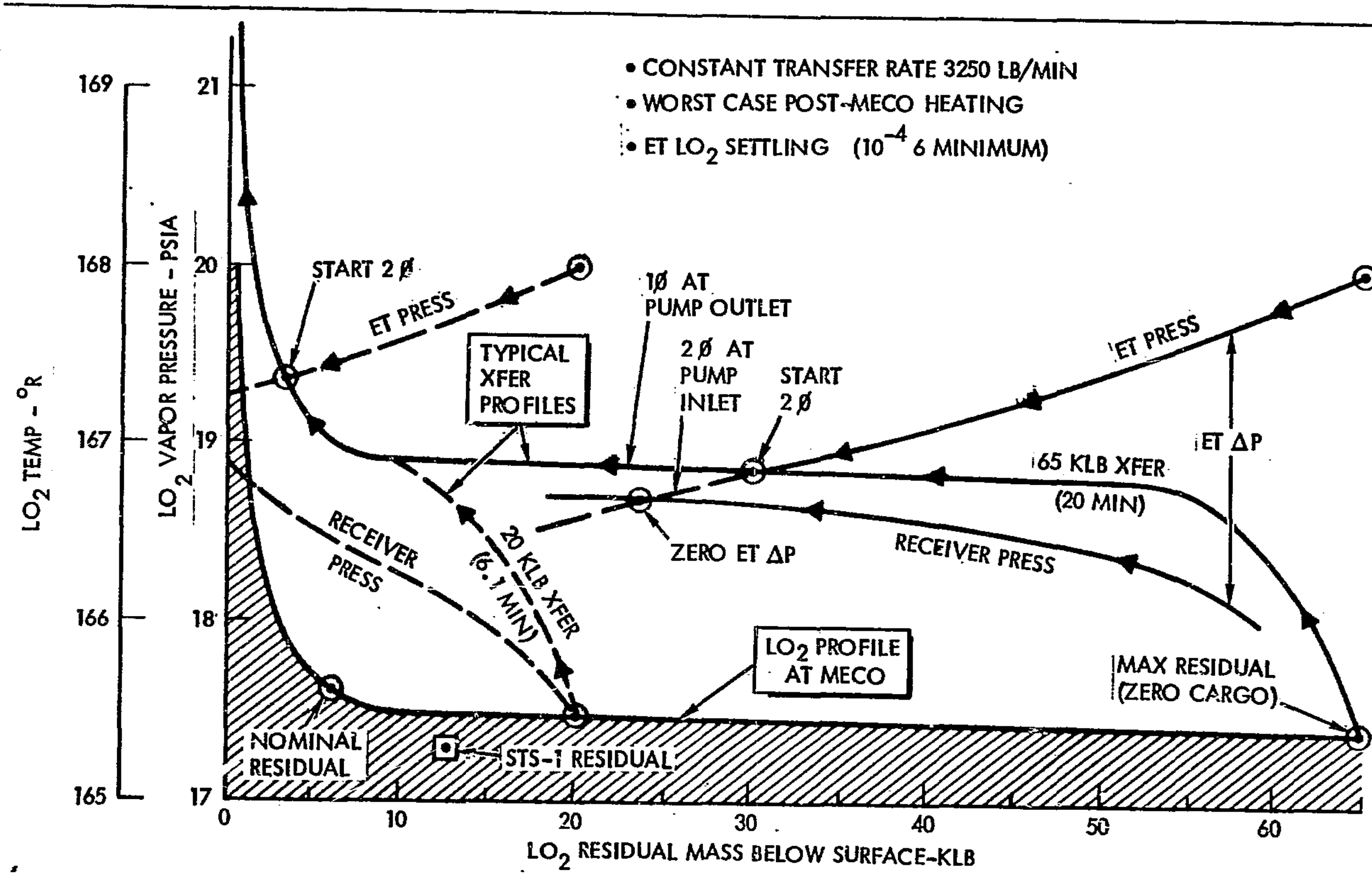
TYPICAL LO_2 VAPOR PRESSURE PROFILES



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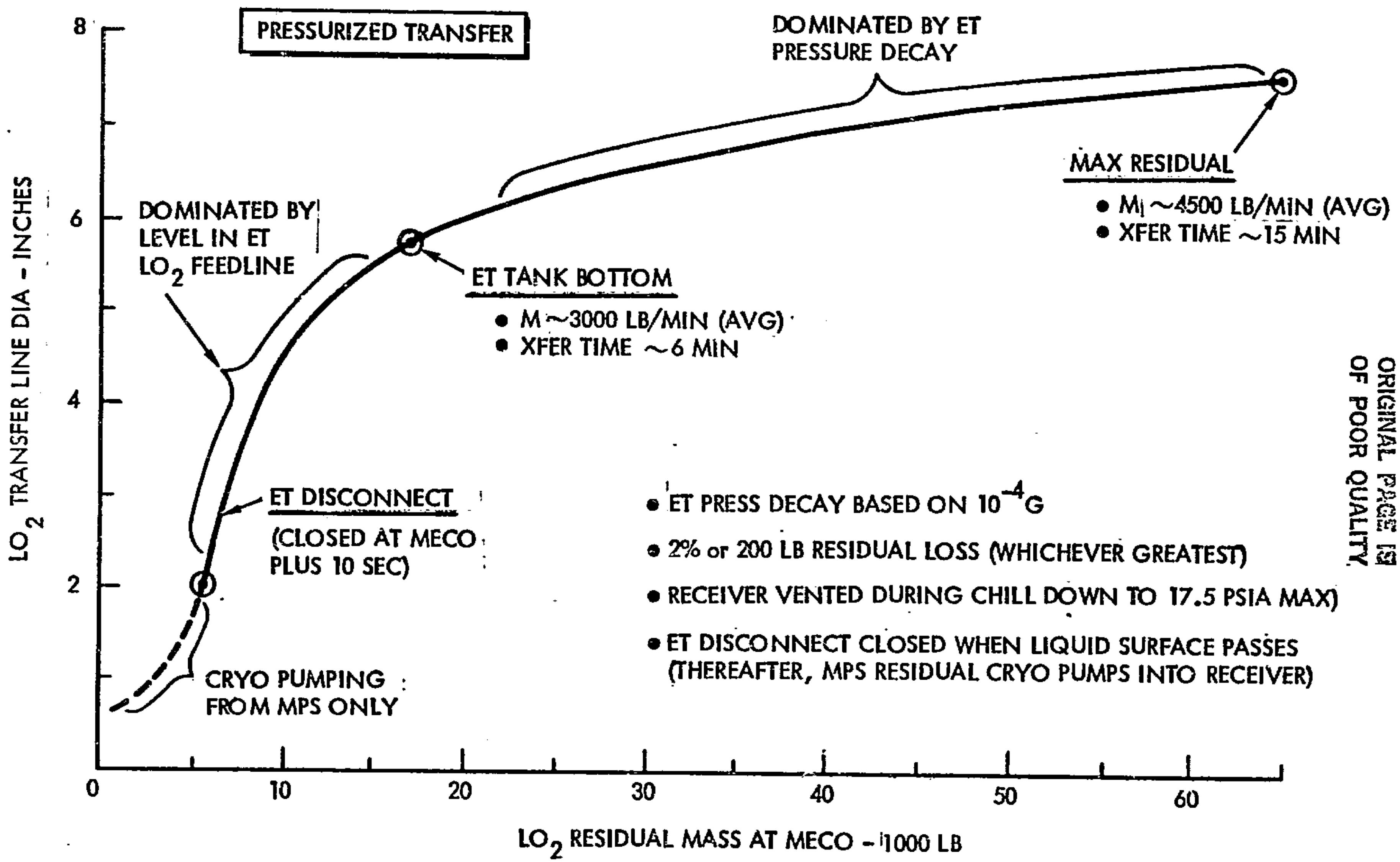
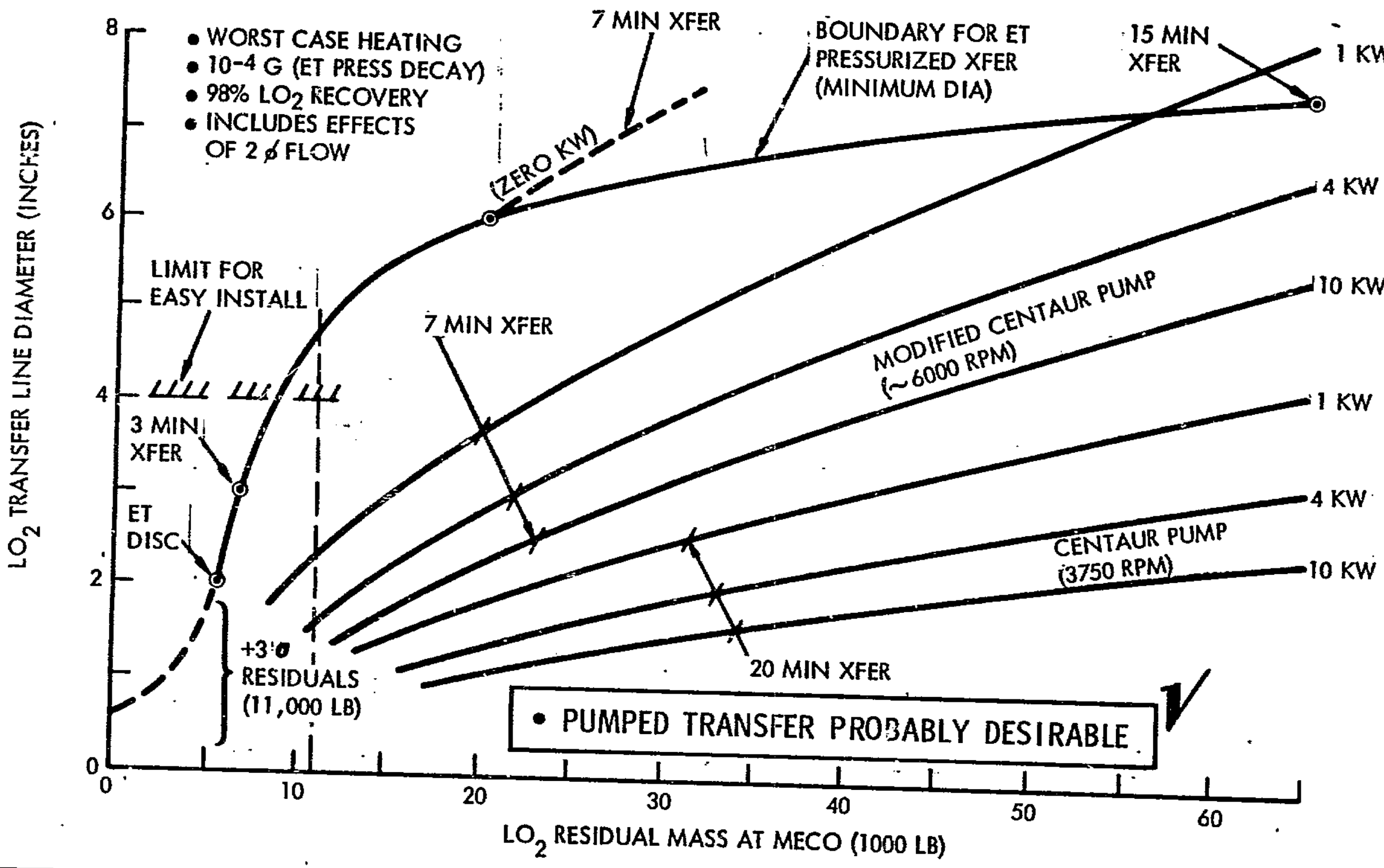
LO_2 TRANSFER LINE SIZE



LO_2 TRANSFER BOOST PUMP TRADE



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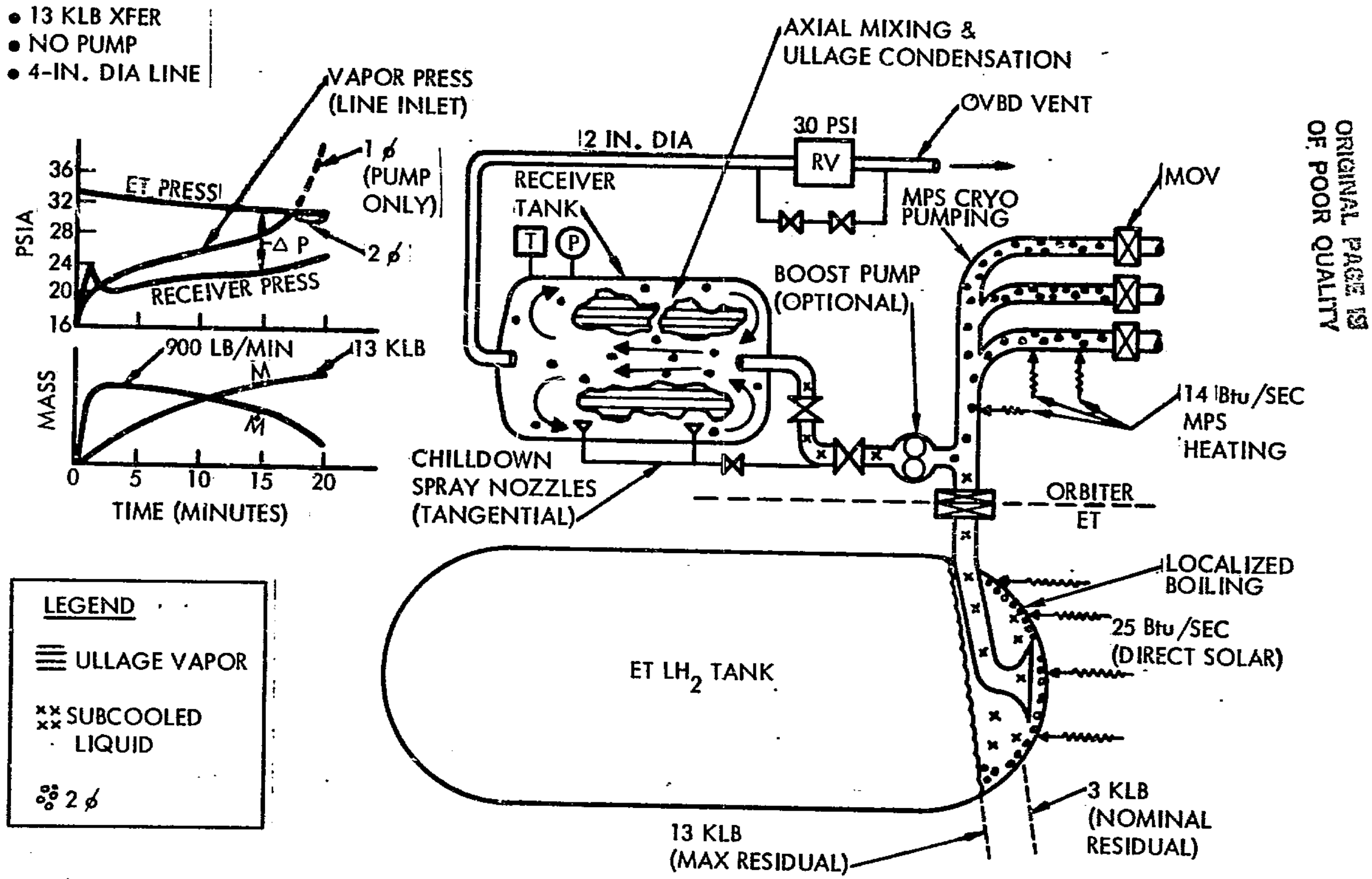
ET LH_2 TRANSFER PHENOMENA



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Space Operations/Integration & Satellite Systems Division

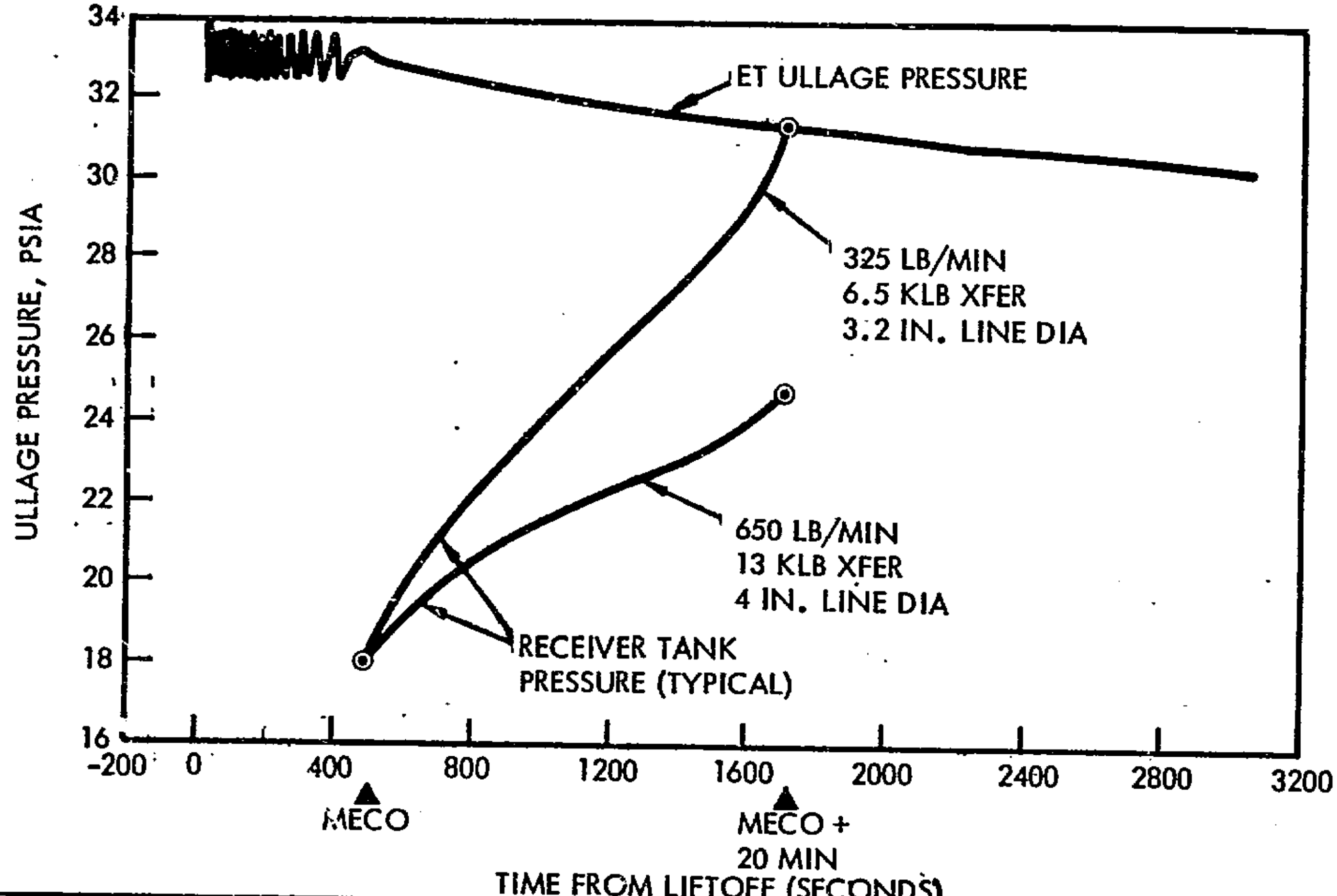
Rockwell International

101SSD21994

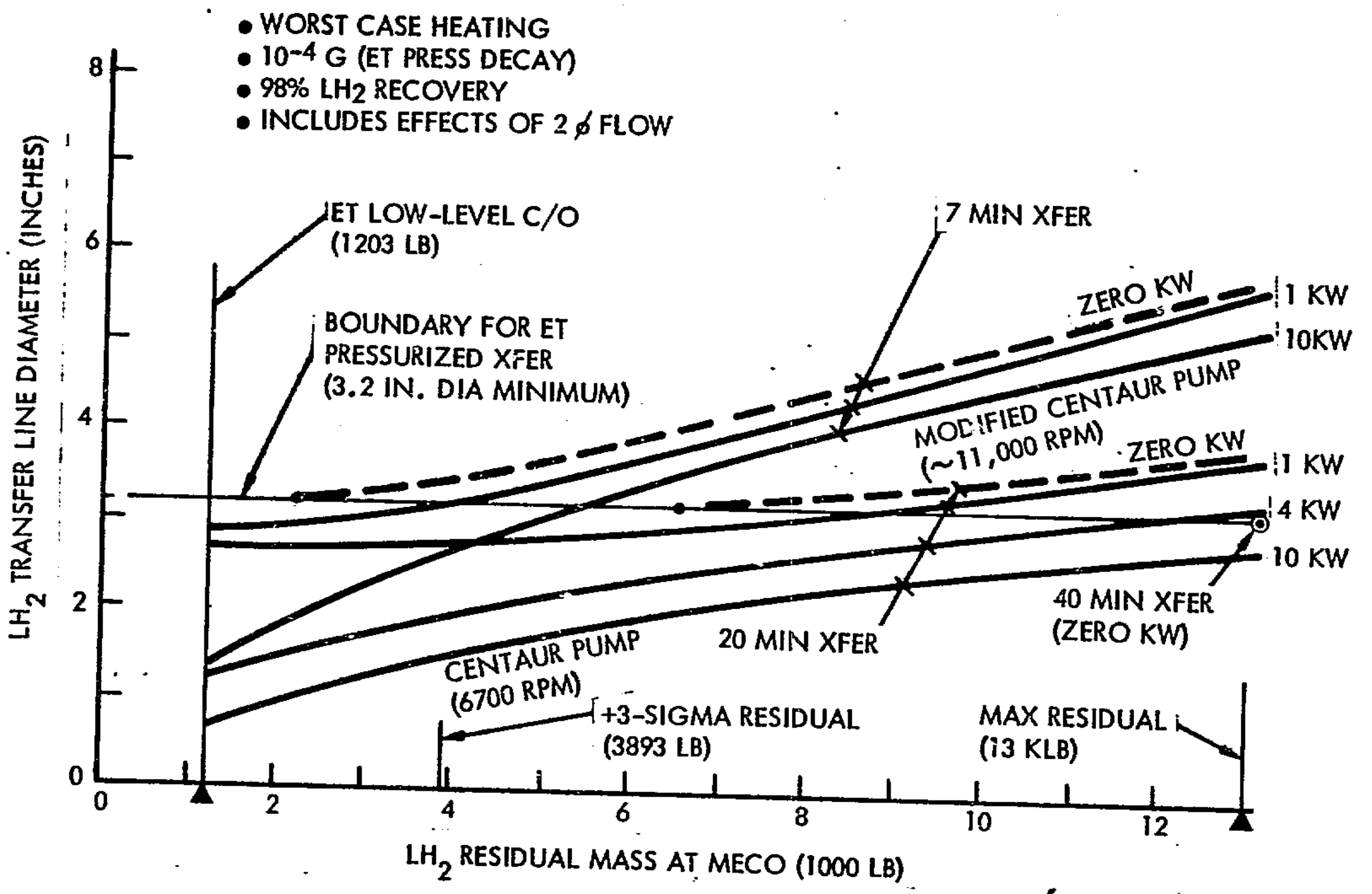
LH_2 TRANSFER PRESSURE HISTORIES

- PRESSURIZED XFER
- 98% RESIDUAL RECOVERY
- COMPUTER SIMULATION OF ET ULLAGE PRESSURE HISTORY
- 10^{-4} G POST-MECO ACCELERATION

LH2 PRESSURIZATION SYSTEM PERFORMANCE FOR BRM-1
PRESSURANT SUPPLY CONDITIONS BASED ON JULY, 1980 INFLUENCE COEFF
FCV ORIFICES -5400, -5410



LH_2 TRANSFER BOOST PUMP TRADE



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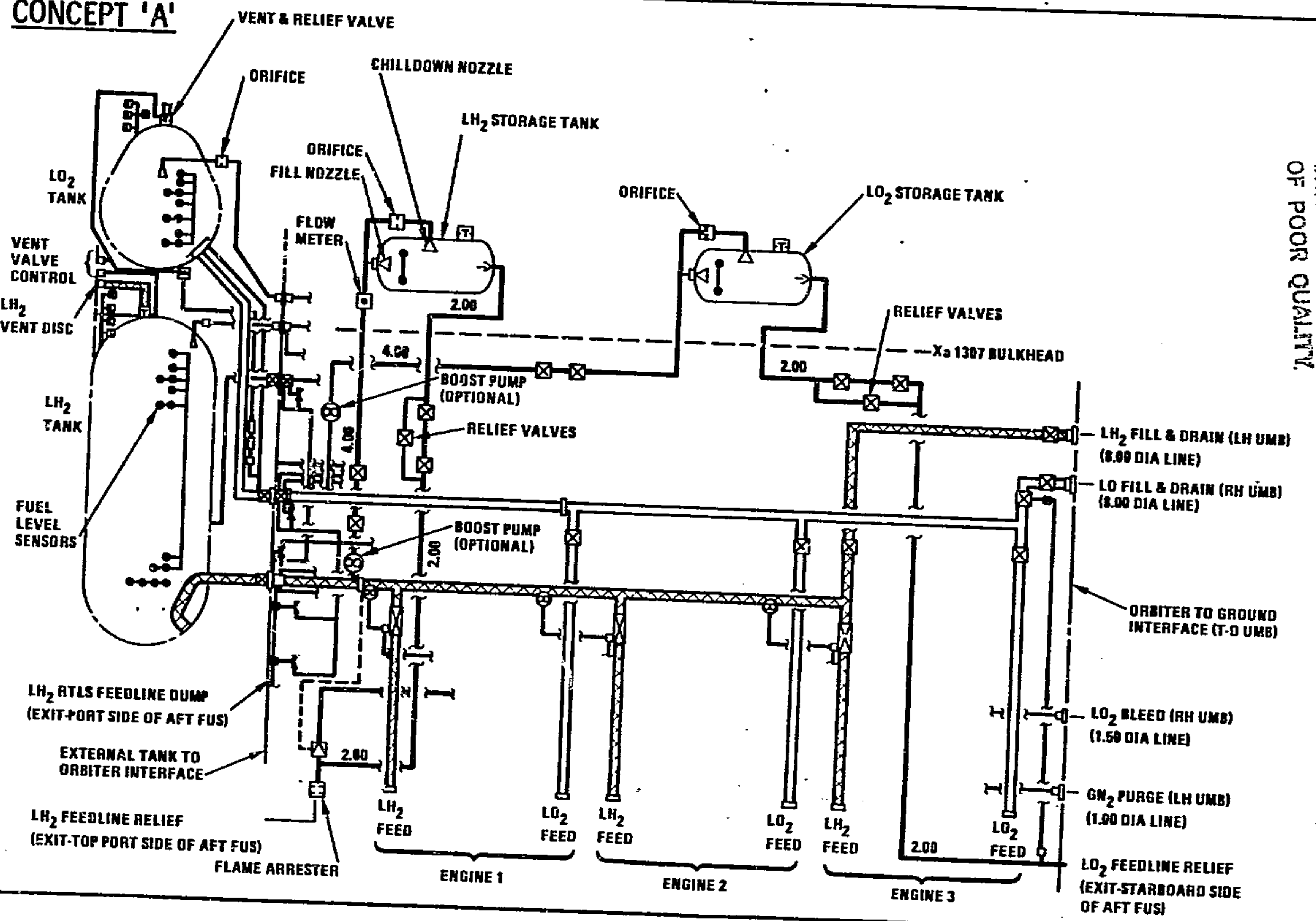
PRESSURIZED TRANSFER THE WAY TO GO

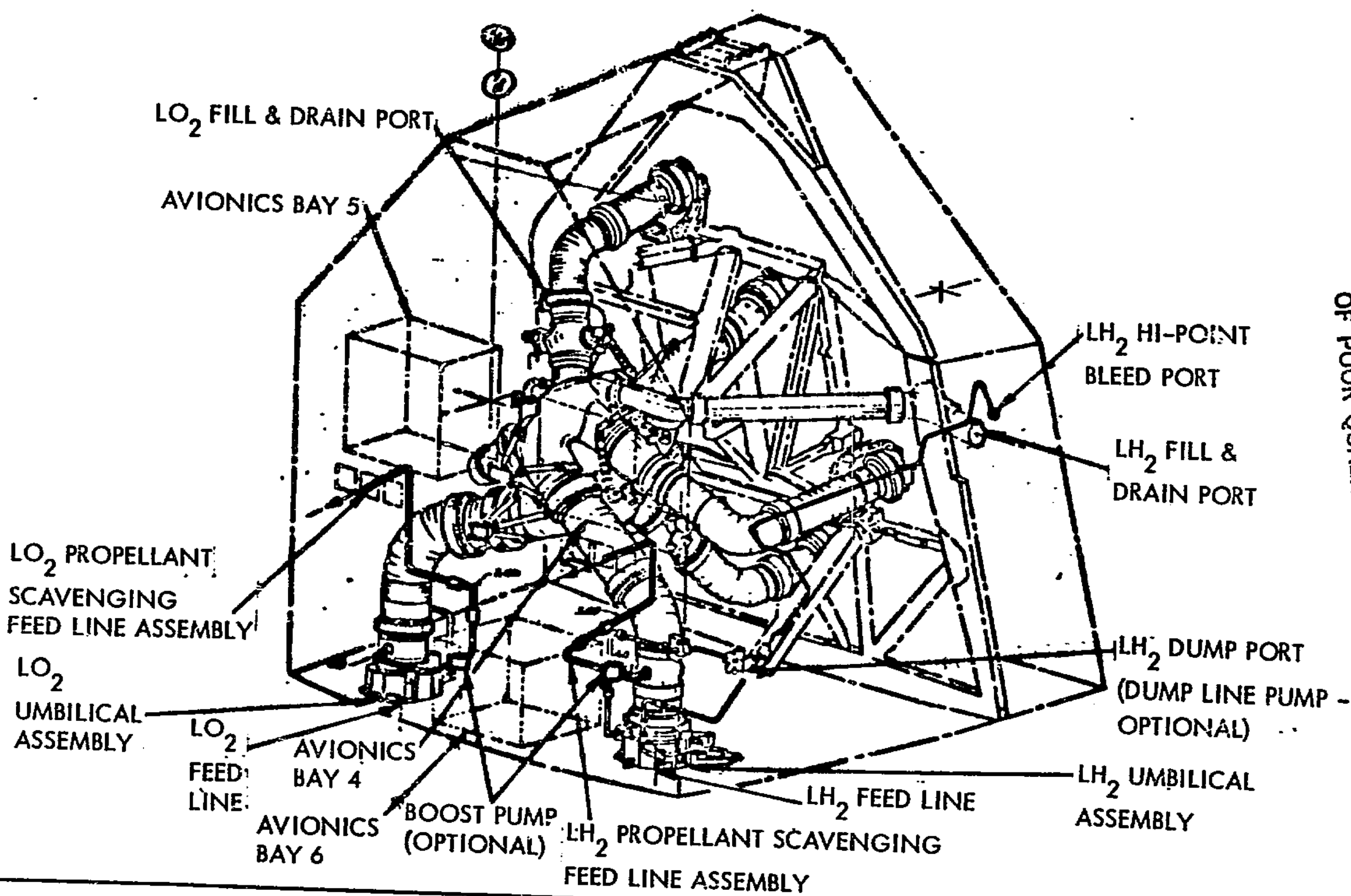
PROPULSION/SCAVENGING SYSTEM SCHEMATIC

CONCEPT 'A'



ORBITER - MAIN PROPULSION SYSTEM.

CONCEPT 'A'



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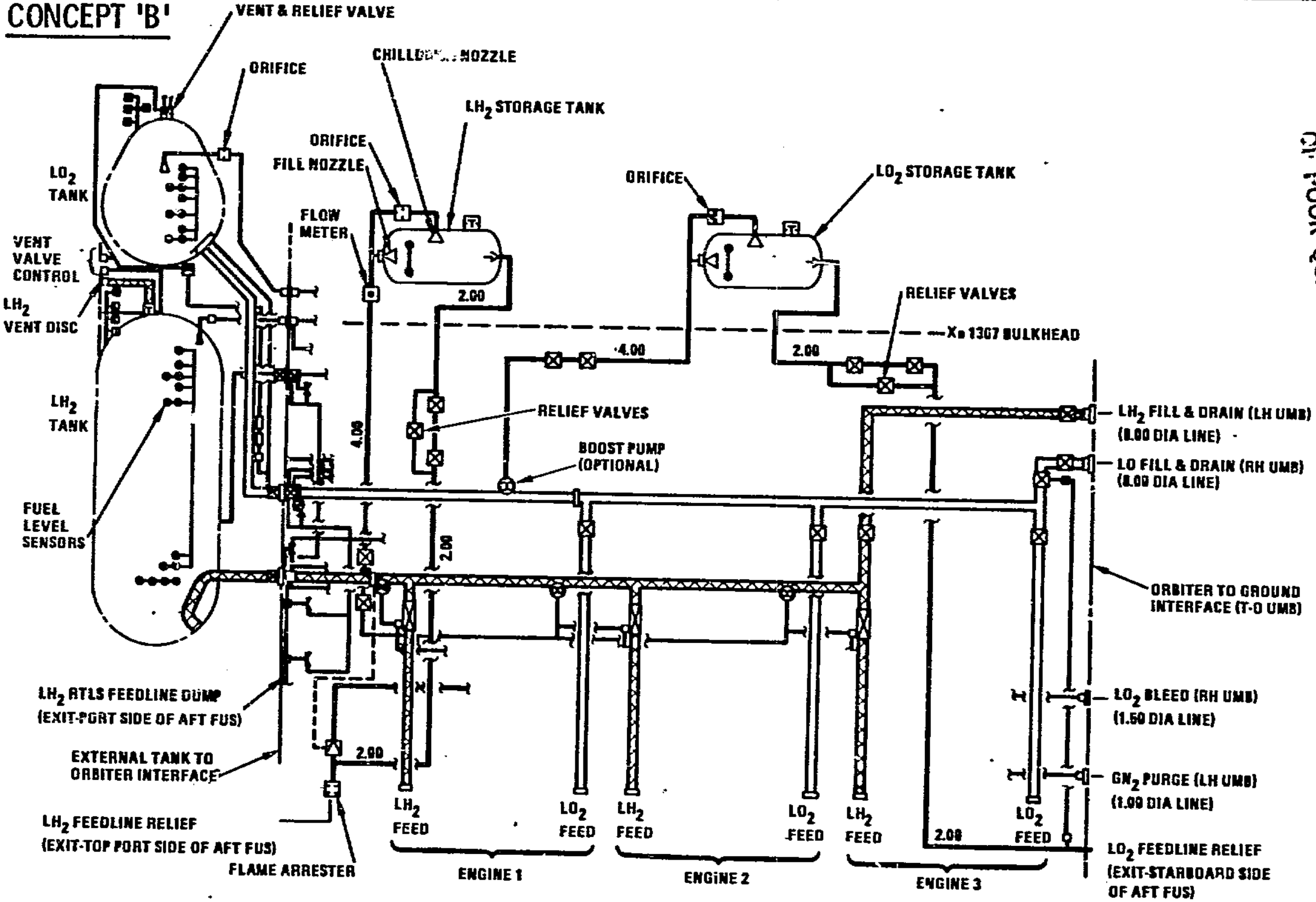
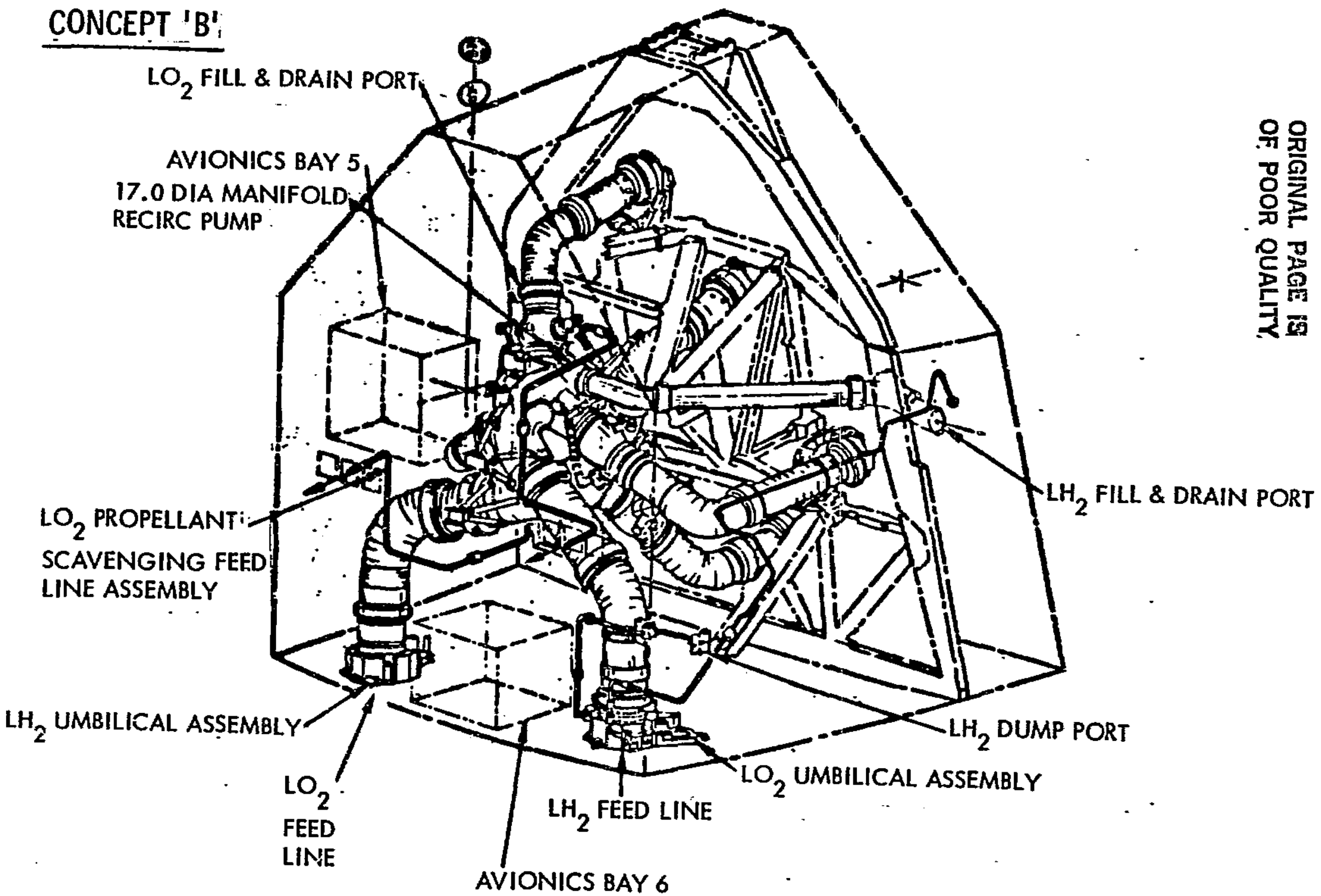
PROPULSION/SCAVENGING SYSTEM SCHEMATIC

CONCEPT 'B'



ORBITER - MAIN PROPULSION SYSTEM

CONCEPT 'B'



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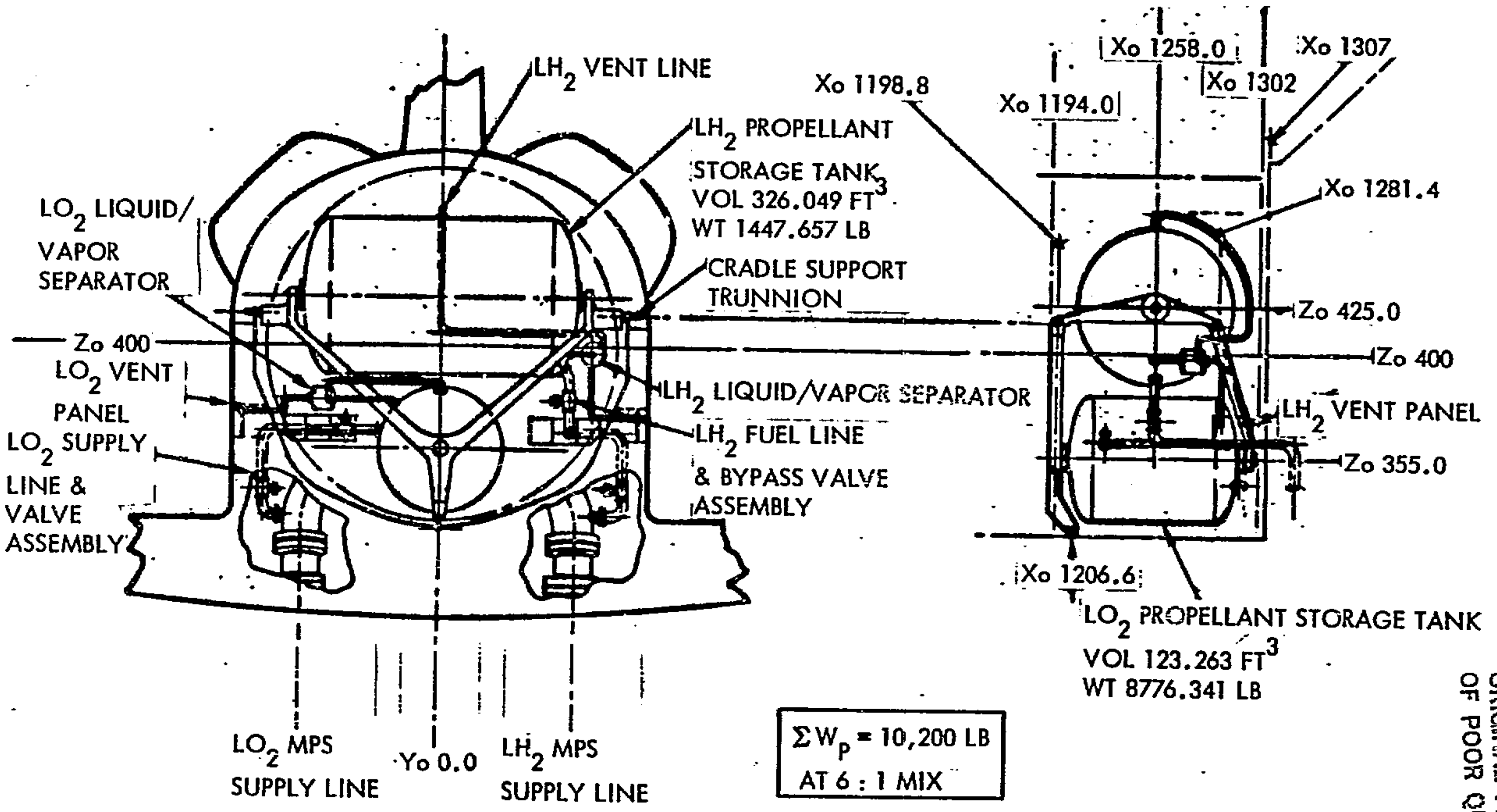
CONVENTIONAL TANK CONCEPT



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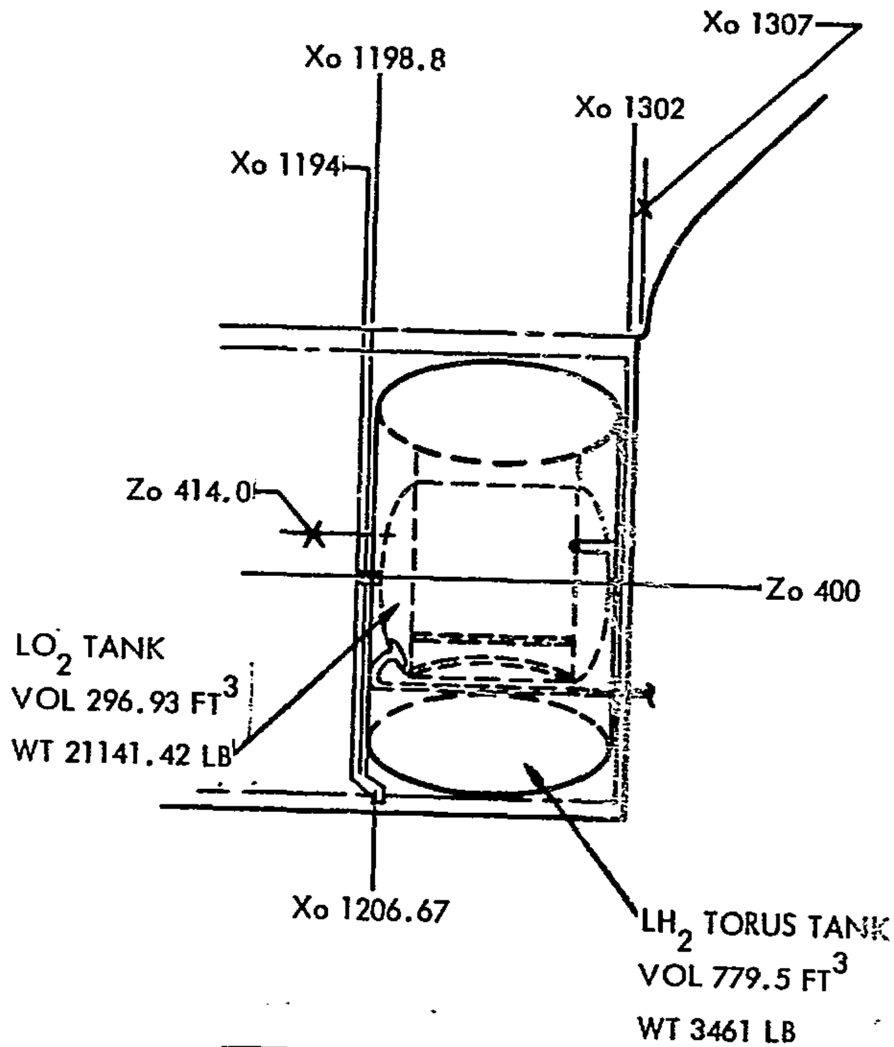
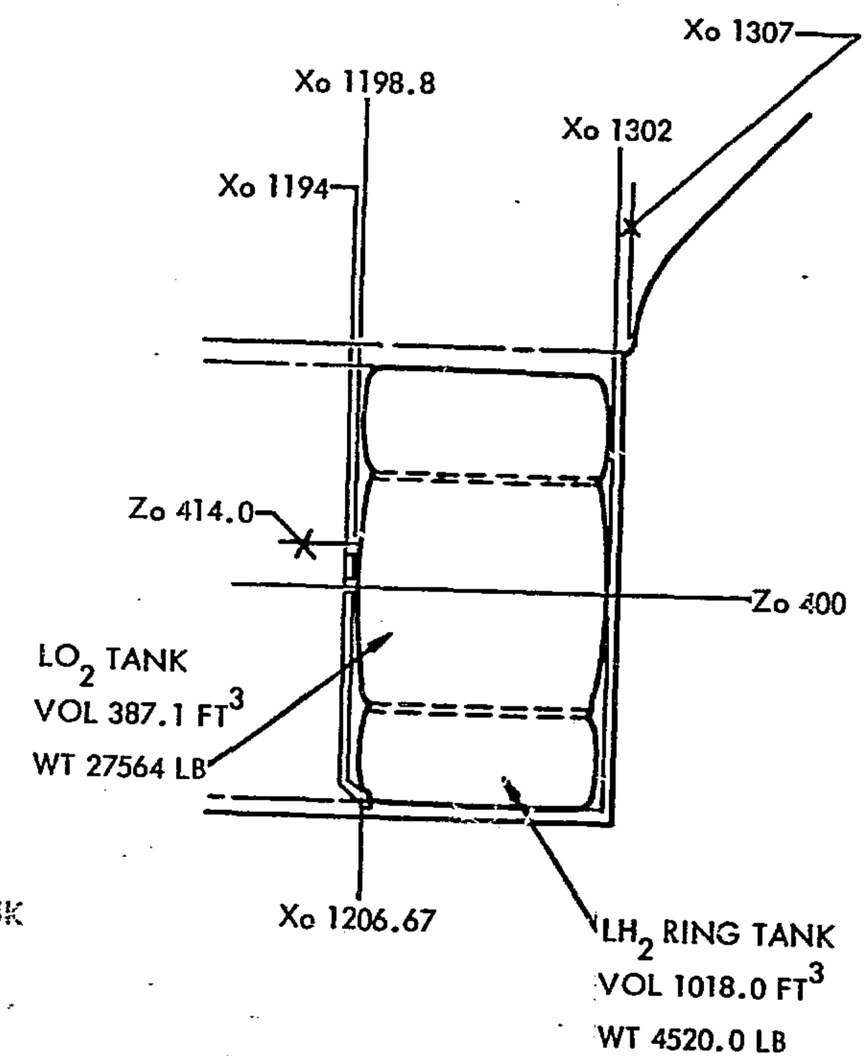
TORUS & RING TANK CONCEPTS

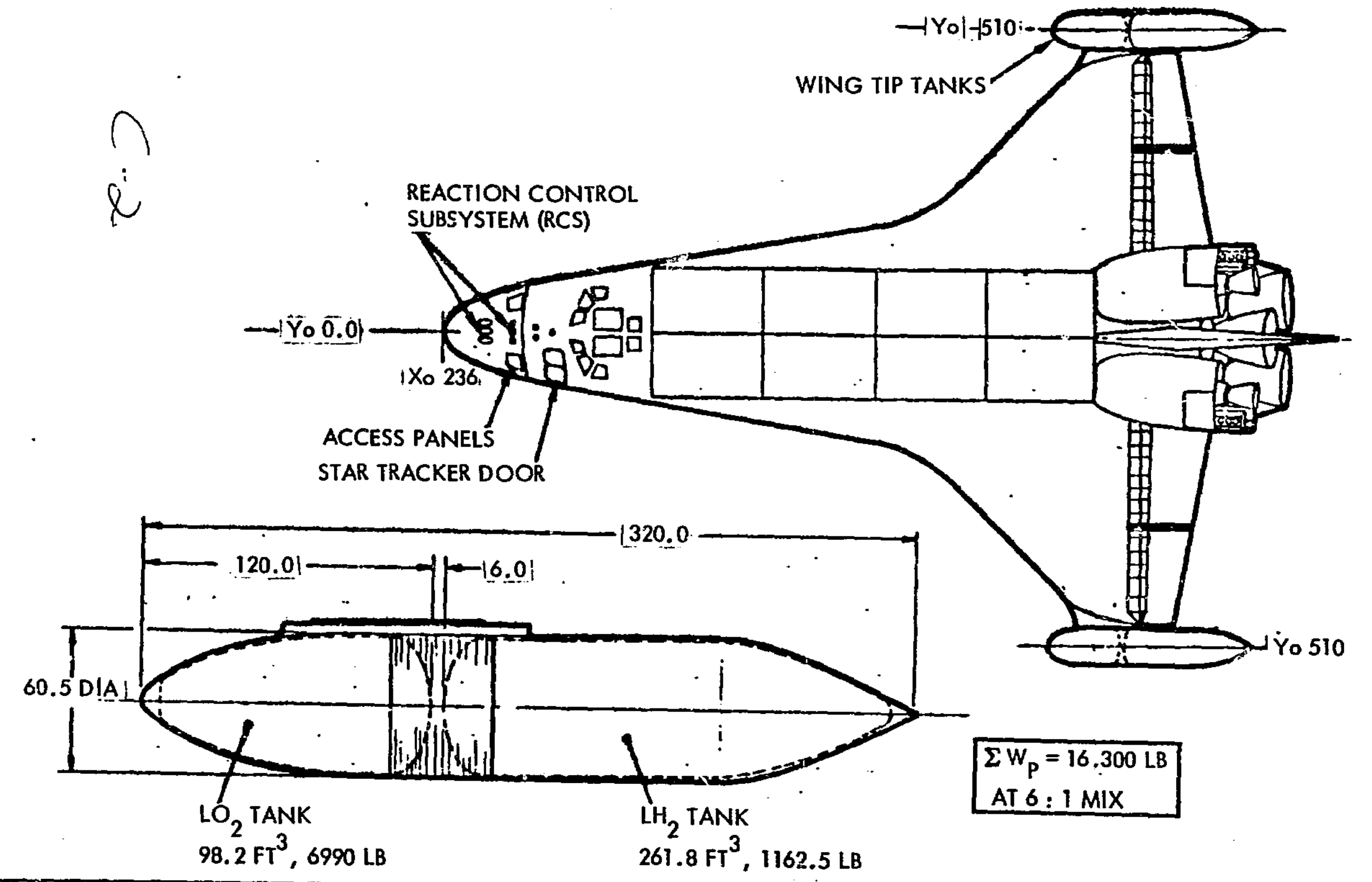


ΣW_p = 24,600 LB AT 6 : 1 MIX

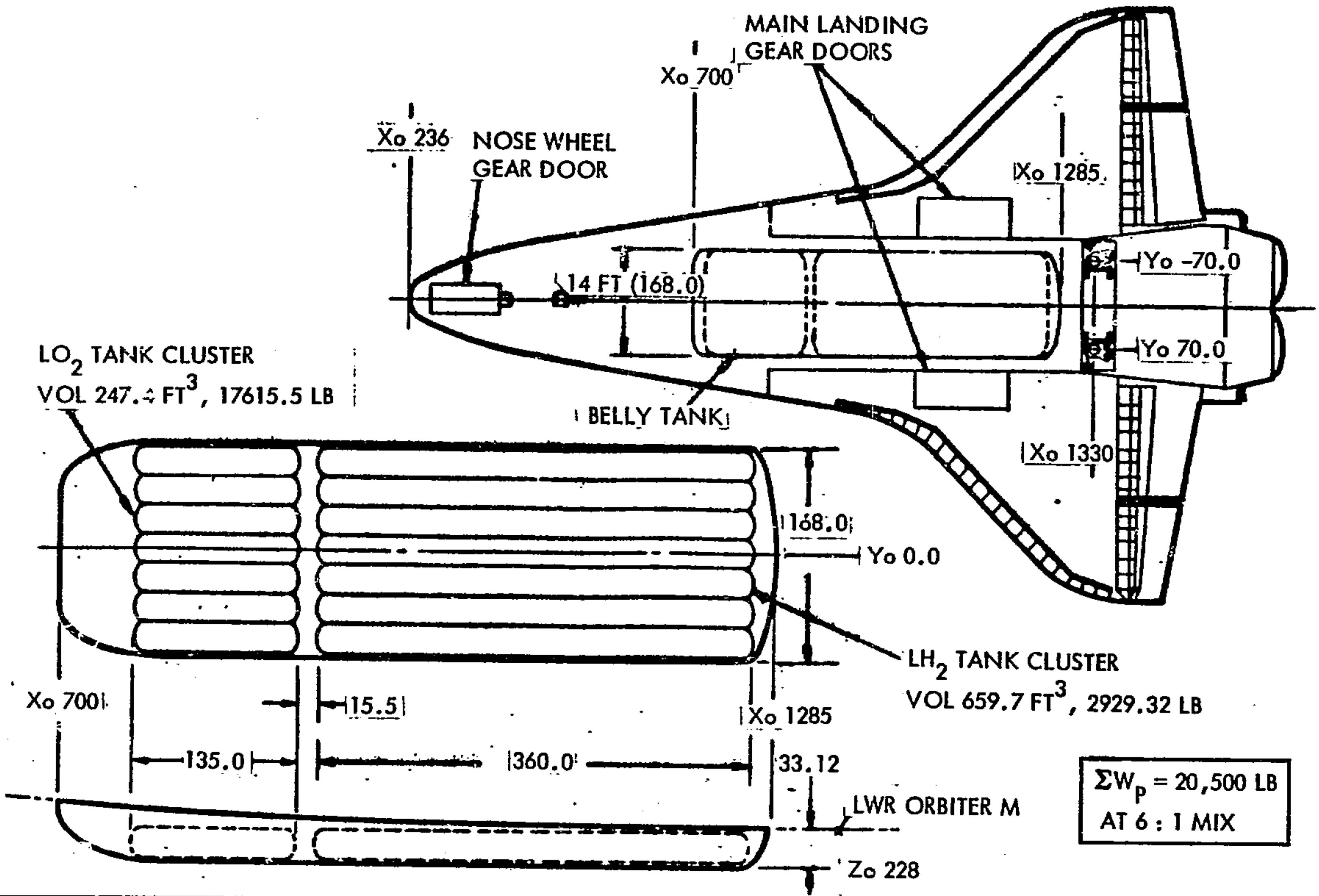


ΣW_p = 32,000 LB AT 6 : 1 MIX

TIP TANK CONCEPT



BELLY TANK CONCEPT



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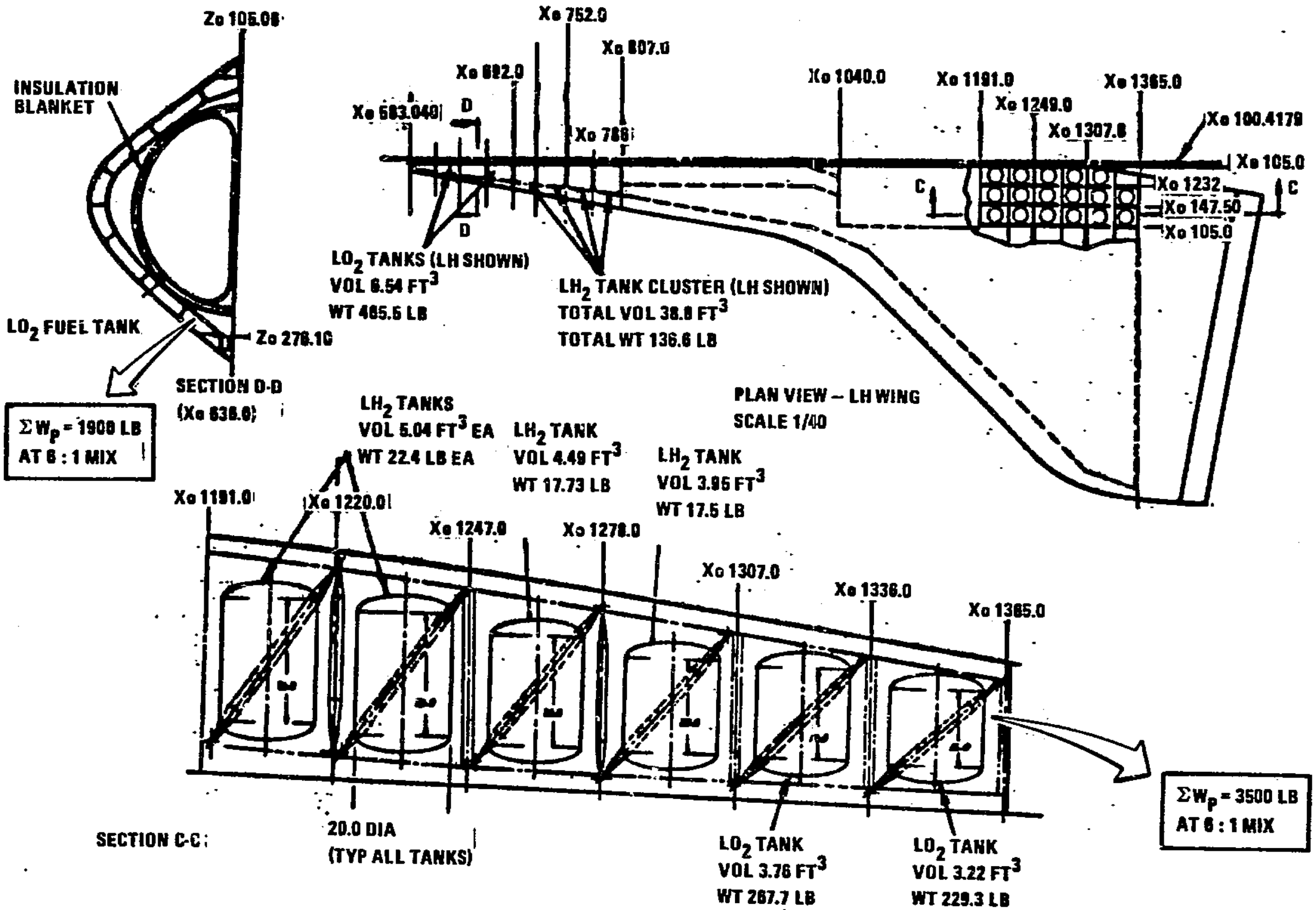
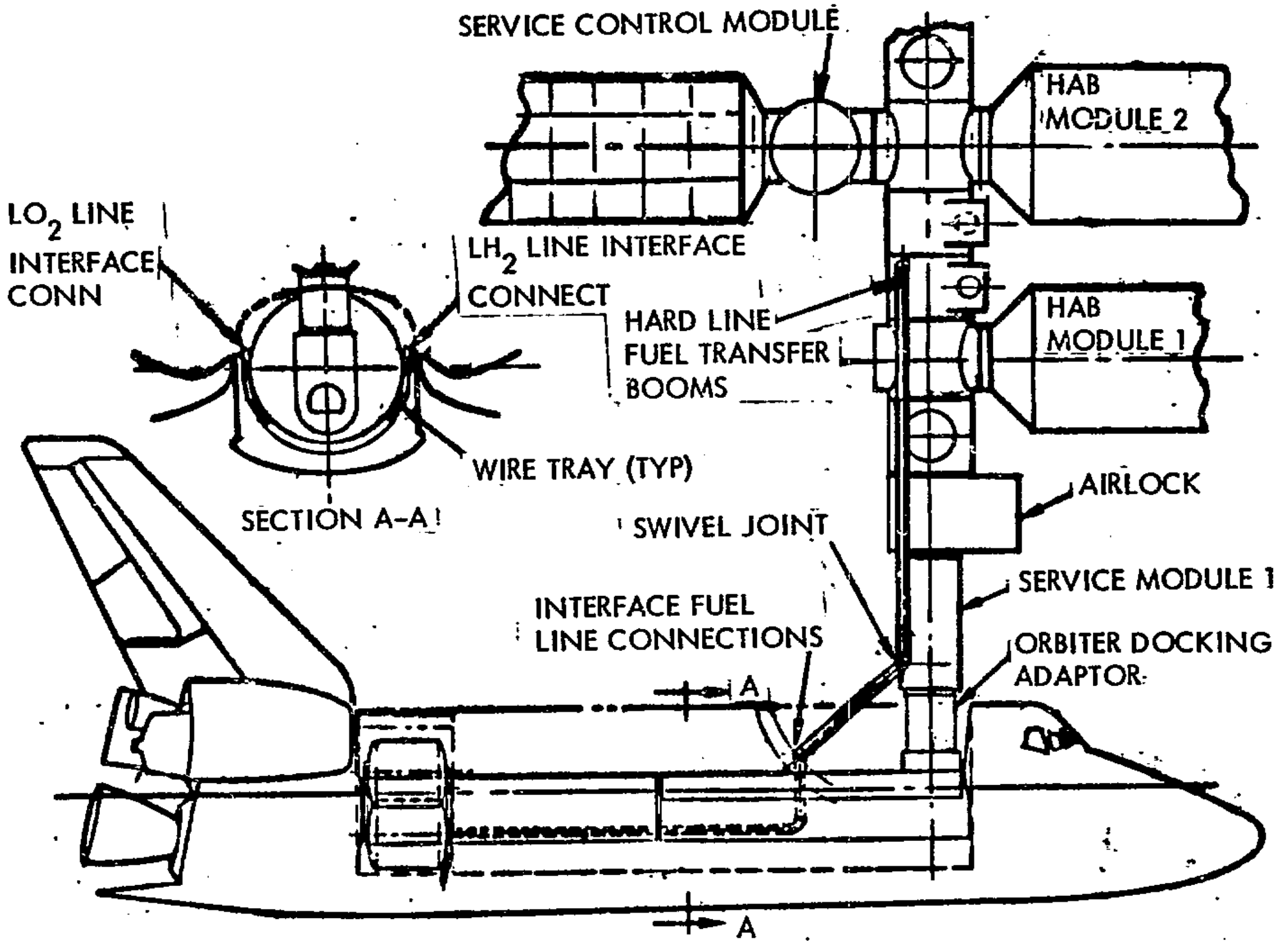
$\Sigma W_p = 20{,}500$ LB
AT 6 : 1 MIX

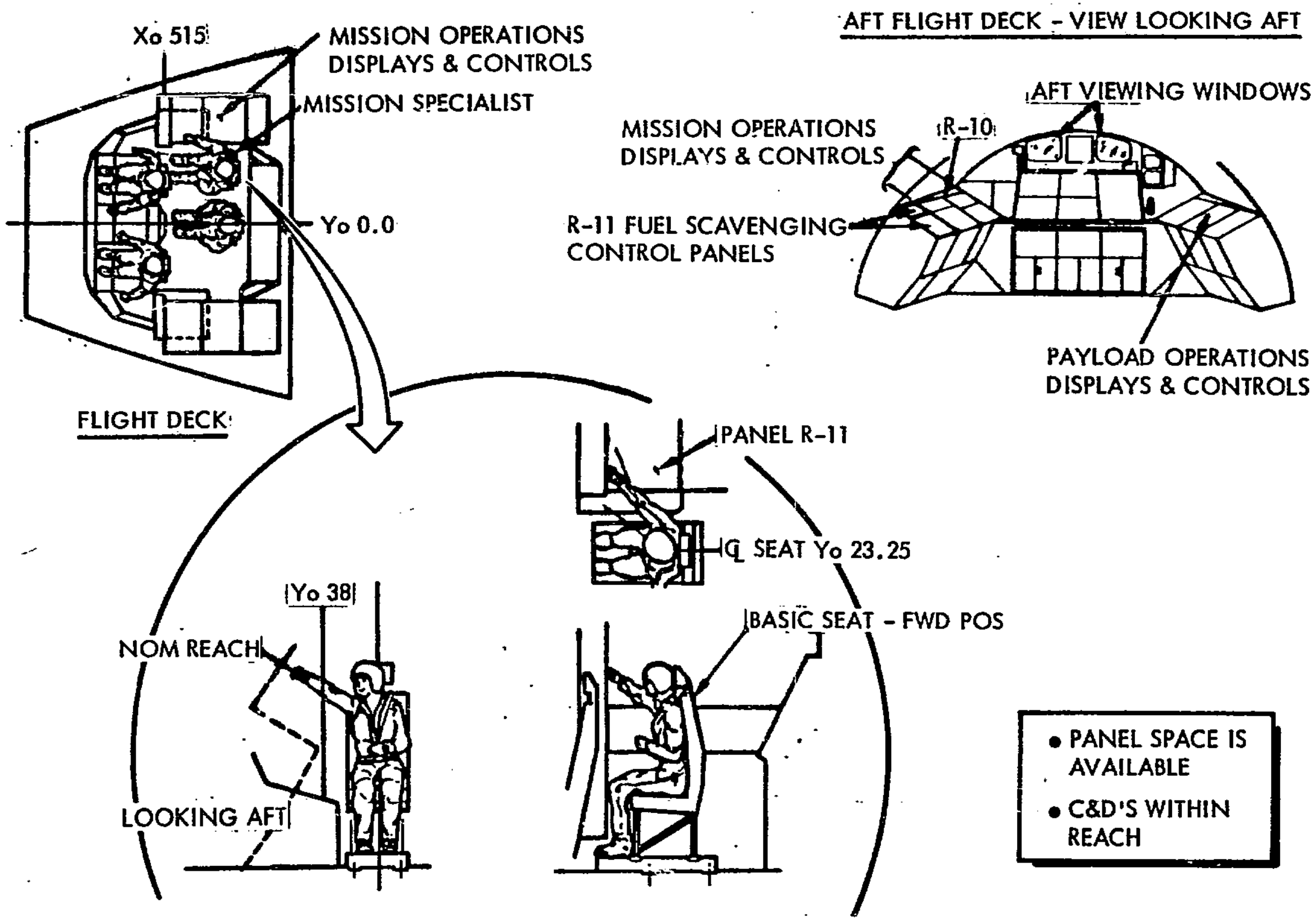
WING AND GLOVE STORAGE TANK CONCEPT



ON-SITE FUEL TRANSFER CONCEPT



CREW CONSIDERATIONS



- PANEL SPACE IS AVAILABLE
- C&D'S WITHIN REACH

REPRESENTATIVE SCAVENGING SEQUENCE

ASSUMPTIONS

- MAXIMUM RESIDUALS (65K LOX, 13K LH2)
- 8 MINUTE XFER TIME
- PRESSURIZED LH2 XFER (6 IN. DIA LINE)
- PUMPED LOX XFER (6 KW, 6 IN. DIA LINE)
- SECONDARY ZONE ET IMPACT
- SETTLING THRUST, 5×10^{-3} G (2 PRIMARY RCS THRUSTERS)
- LH2 RECEIVER TANK PRECHILLED TO 160°R (LN2)

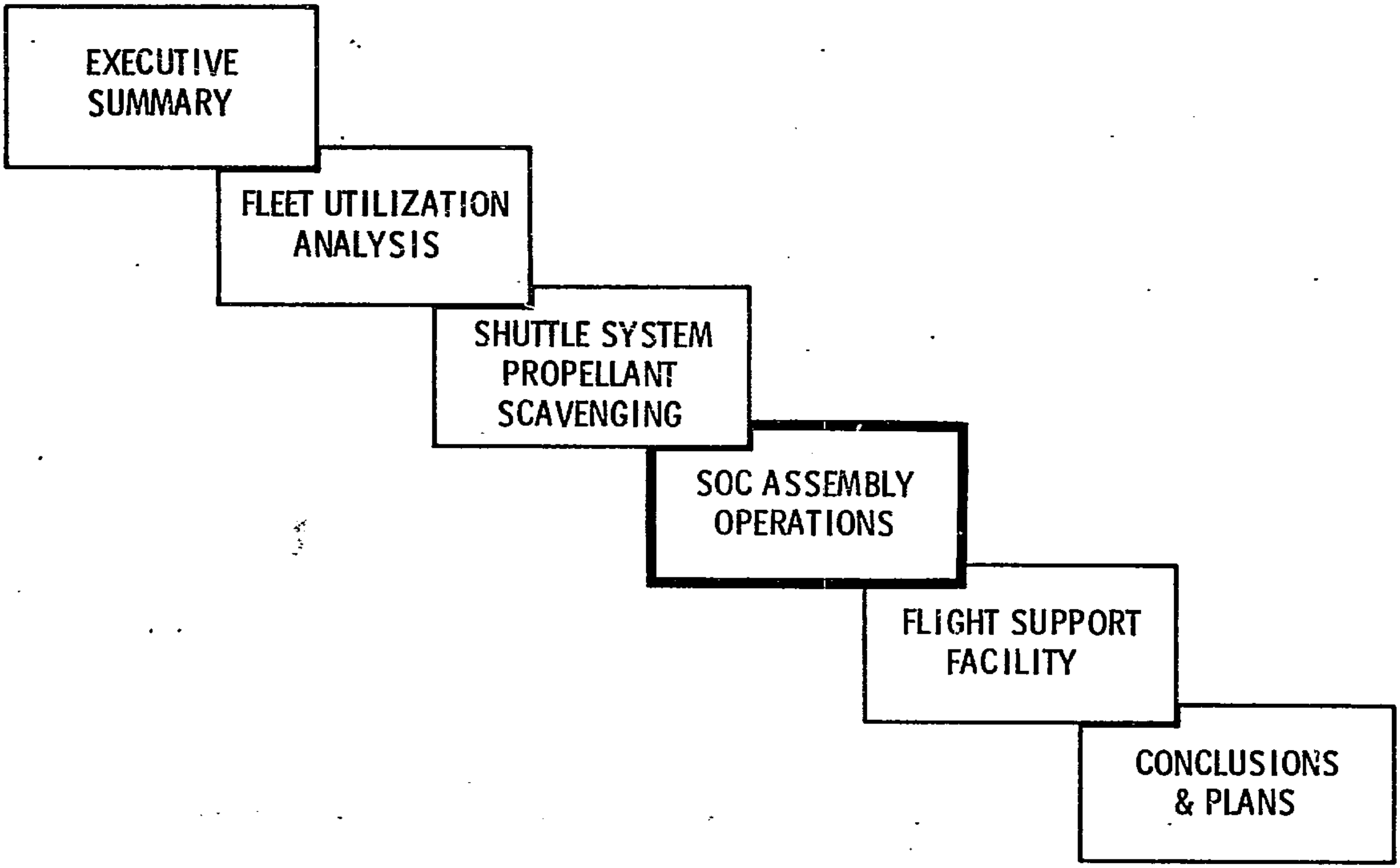
TIME	EVENT
• L/O + 100 SEC	• START VENTING RECEIVER TANKS
• MECO	• TURN ON RCS SETTLING THRUSTERS
• MECO + 10 SEC	• VERIFY RECEIVER TANKS BELOW ONE PSIA • CLOSE RECEIVER VENT VALVES
• MECO + 15 SEC	• OPEN ISO-VALVES TO START CHILLDOWN OF LOX & LH2 XFER LINES • MONITOR SYSTEM FLOWS/TEMPS/PRESS
• MECO + 60 SEC	• OPEN MAIN FILL VALVES • START LOX PUMP • MONITOR SYSTEM FLOWS/TEMPS/PRESS
• MECO + 460 SEC	• STOP LOX PUMP AND CLOSE ET DISCONNECT WHEN ET LINE DEPLETED (FLOWRATE < 5% AS RECEIVER PRESSURE REACHES 26 PSIA). ALLOW CRYOPUMPING FROM MPS INTO RECEIVER TANK • STOP RCS SETTLING THRUST WHEN LH2 ET DEPLETED (EXCESSIVE BUBBLES IN XFER LINE) AND ALLOW LH2 SIPHON TO DRAIN (AIDED BY AERO-DRAG)
• MECO + 480 SEC	• CLOSE LH_2 ET DISCONNECT WHEN LH_2 SIPHON DEPLETED (FLOWRATE (FLOWRATE < 5% OR RECEIVER PRESS REACHES 26 PSIA). ALLOW CRYOPUMPING FROM MPS INTO RECEIVER TANK • SEPARATE ET • TERMINATE CRYOPUMPING BY CLOSING XFER LINE ISO-VALVES WHEN RECEIVER TANK PRESSURES REACH 28 PSIA (OR MPS PRESSURES EQUAL RECEIVER PRESSURES.
• MECO + 1200 SEC	• OMS I BURN
• MECO + 1400 SEC	• VENT MPS PLUMBING AND SECURE XFER SYSTEM

SAFETY CONSIDERATIONS

ISSUE	COMMENT
LINE INTEGRITY	QUALIFY TO MPS PLUMBING REQ
MPS INTEGRITY	MULTIPLE ISOLATION VALVES
VALVE MALFUNCTION	REDUNDANT VALVING
O_2 AND H_2 LEAKAGE	GN_2 PURGE ON THE PAD; MINIMAL HAZZARD IN SPACE
SAFEING FOR RE-ENTRY	VENT SYSTEM TO SPACE, PRESS TO 16 PSIA WITH INERT GAS
ET IMPACT	ACCEPTABLE IMPACT ZONES ARE ACHIEVABLE
MECO CHANGE	LESS THAN 1 SECOND CHANGE REQUIRED
RCS MODS	WITHIN THE COMPLEXITY LEVEL OF CURRENT SYSTEM
CREW OPERATIONS	MINIMAL ACTION REQUIRED BEFORE MECO
ORBITER ENGINE OUT	SHUTTLE E/O TOLERANCE INCREASED WITH "DRY LAUNCH" CONCEPT
LO_2 AND LH_2 ABORT DUMPING	NONE REQUIRED WITH "DRY LAUNCH" CONCEPT

SUMMARY

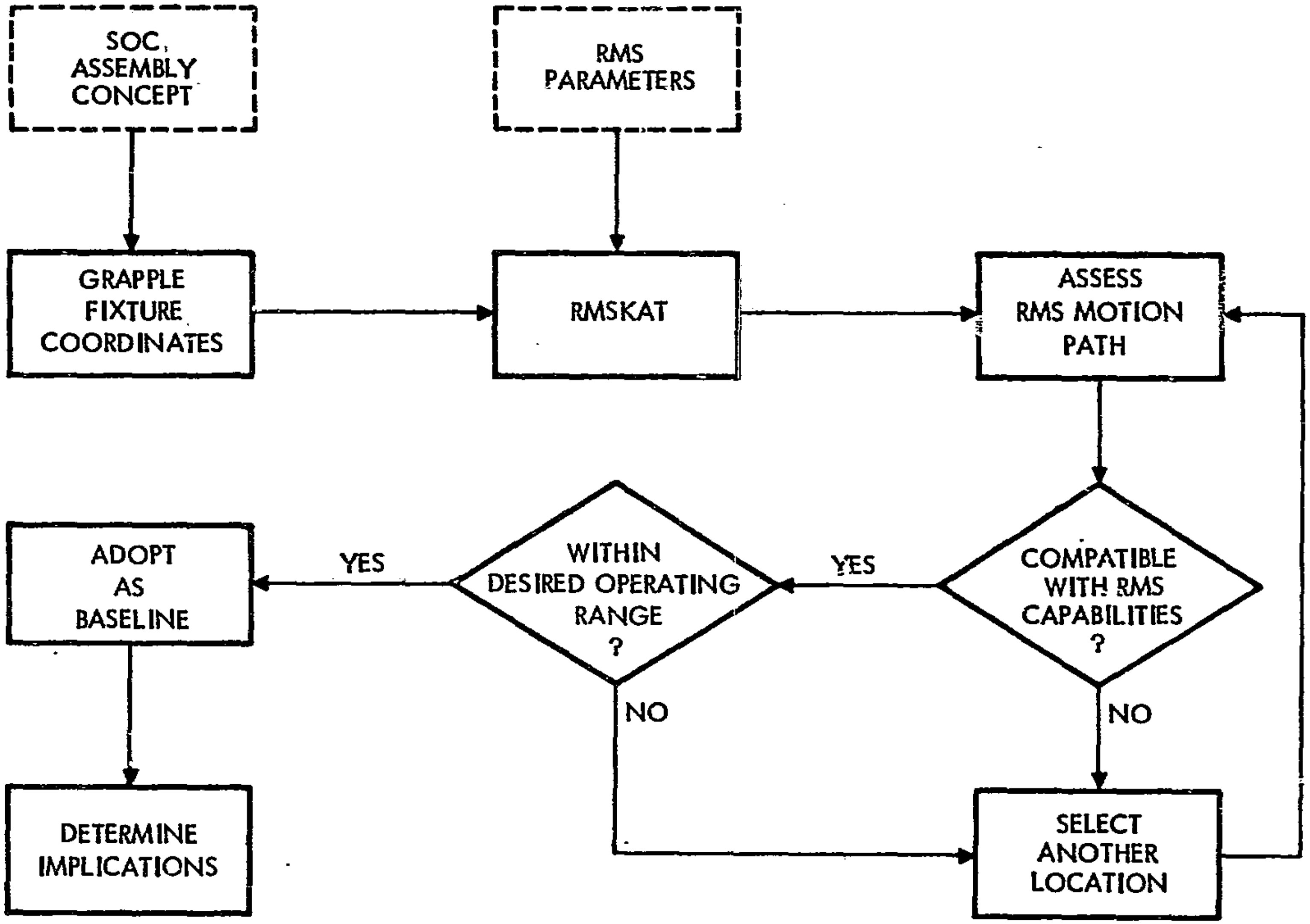
- ESTABLISHED SUBORBITAL ET PROPELLANT RECOVERY AS A VIABLE CONCEPT
  - PROPELLANT TRANSFER ACHIEVABLE WITHIN PRACTICAL TIMES
  - ULLAGE THRUSTING REQUIREMENTS CAN BE MET BY PRIMARY RCS
  - PLUMBING REQUIREMENTS CAN BE SATISFIED WITHIN ORBITER SPACE/VOLUME CONSTRAINTS
  - ET IMPACT ZONES ARE ACCEPTABLE
  - EFFECTS ON SHUTTLE PAYLOADS ARE NEGLIGIBLE
- WIDE RANGE OF APPLICATIONS ARE POSSIBLE
  - BEST APPLICATION IS TRAFFIC DEPENDENT
- NEXT STEP . . . . FURTHER HARDWARE DEFINITION AND STUDY PRELIMINARY OF COST IMPLICATIONS


EXECUTIVE SUMMARY
FLEET UTILIZATION ANALYSIS
SHUTTLE SYSTEM PROPELLANT SCAVENGING
SOC ASSEMBLY OPERATIONS
FLIGHT SUPPORT FACILITY
CONCLUSIONS & PLANS

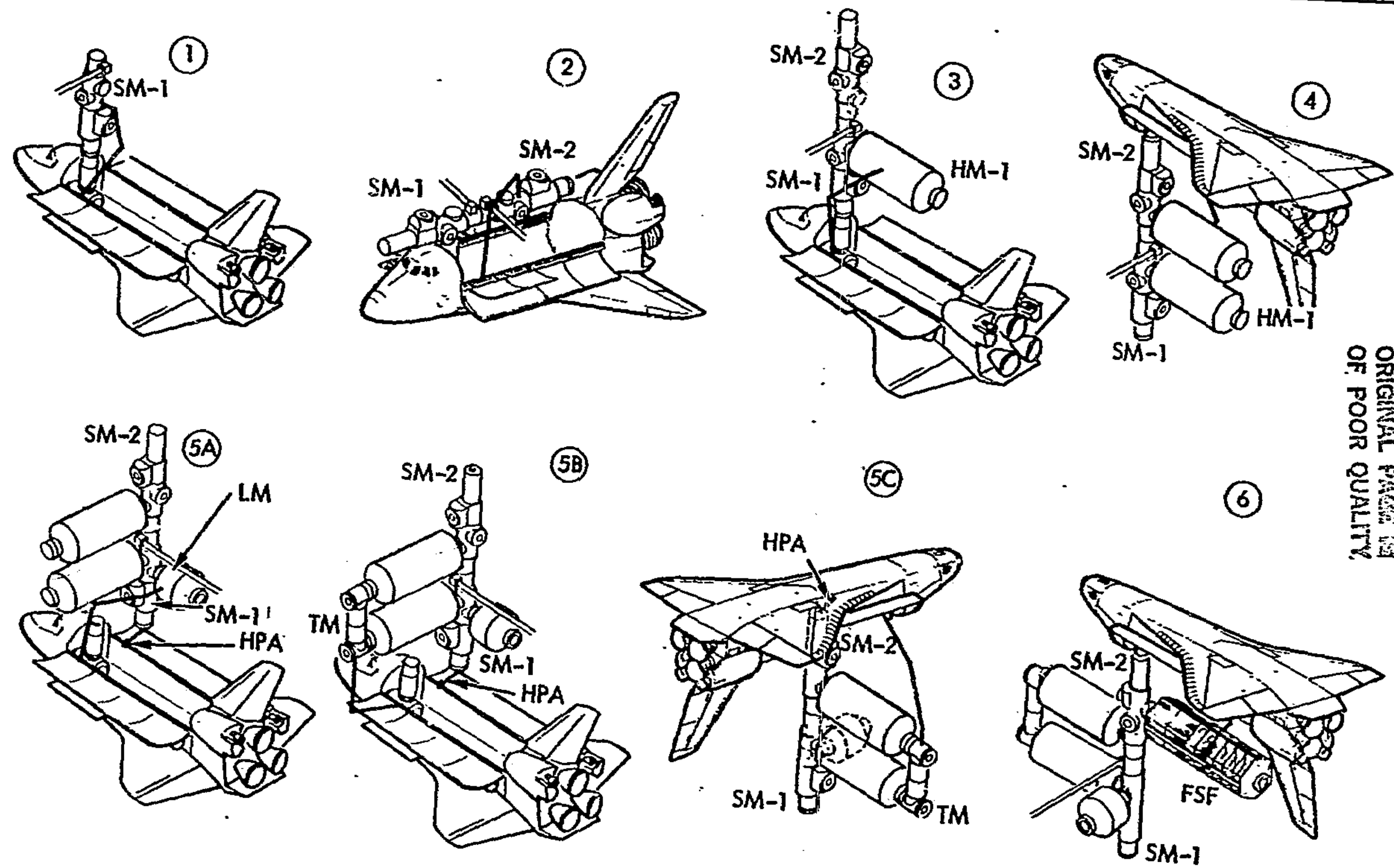
TASK 2 -- SOC ASSEMBLY OPERATIONS OBJECTIVES

- CONFIRM CAPABILITY OF RMS TO ASSEMBLE SOC
- DETERMINE ASSEMBLY OPERATIONAL IMPLICATIONS
- DETERMINE IMPLICATIONS TO SOC MODULES

TASK 2 - SOC ASSEMBLY OPERATIONS APPROACH



SOC ASSEMBLY



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RMS/SOC ASSEMBLY ISSUES

- RMS REACH & JOINT LIMITS DURING SOC ASSEMBLY TRAJECTORIES
  - START & FINAL END EFFECTOR LOCATIONS
  - IN-BETWEEN POINTS
- PRACTICAL LOCATION ZONES FOR GRAPPLE FIXTURES
- BERTHING ACCURACY VS GRAPPLE FIXTURE LOCATION
- ASSEMBLY AIDS -- DM, HPA, PIDA
- OPERATOR VISIBILITY
- COLLISION AVOIDANCE DURING ASSEMBLY

RMS PARAMETERS OF MAIN INTEREST

- JOINT ANGLE LIMITS AT BERTHING
  - NO BERTHING IN REACH LIMIT OR SINGULARITY ZONES
  - WRIST YAW ANGLE NOT GREATER THAN ± 60 DEG
  - ELBOW ANGLE NOT LESS THAN - 40 DEG
- GRAPPLE FIXTURE LOCATION
  - WITHIN 5% (OF PAYLOAD LENGTH) OF THE Y-Z
  - PLANE OF PAYLOAD CENTER OF MASS
- POSITIONING ACCURACY -- RELATIVE TO ORBITER
  - AUTO MODE: ± 9 INCHES MAX, ± 3 DEGREES MAX } INCLUDES MECHANICAL INACCURACIES & THERMAL DISTORTIONS
  - MAM: FUNCTION OF OPERATOR VISIBILITY

REMOTE MANIPULATOR SYSTEM KINEMATIC ANALYSIS TOOL (RMSKAT)*

- COMPUTER PROGRAM FOR KINEMATIC EVALUATION OF RMS OPERATIONAL ENVELOPES
- RIGID BODY SIMULATIONS ONLY
- GRAPHIC FEED BACK (SOC GRAPHICS MOD IN PROGRESS)
- TWO OPERATING MODES

INPUT

- START & FINAL END EFFECTOR COORDINATES & ORIENTATION IN ORBITER REFERENCE SYSTEM
- RMS JOINT ANGLE SPECIFICATIONS

OUTPUT

- RMS JOINT ANGLE READINGS AT SPECIFIED TIME INTERVALS
- END EFFECTOR COORDINATES & ORIENTATION IN ORBITER REFERENCE SYSTEM

*DEVELOPED WITH DISCRETIONARY FUNDS

RMSKAT SAMPLE OUTPUT

TIME= 0.00 SECONDS

POSDES 1	-1107.000	POSDES 2	25.000	POSDES 3	-566.000	ATTDES 1	270.000	ATTDES 2	0.000	ATTDES 3	270.000
PORPOS 1	-806.985	PORPOS 2	24.999	PORPOS 3	-565.976	PORATT 1	269.999	PORATT 2	0.002	PORATT 3	269.994
GRCMD 1	0.000	GRCMD 2	0.000	GRCMD 3	0.000	GRCMD 4	0.000	GRCMD 5	0.000	GRCMD 6	0.000
RHANGD 1	0.000	RHANGD 2	0.000	RHANGD 3	0.000	RHANGD 4	0.000	RHANGD 5	0.000	RHANGD 6	0.000
GACMD 1	-52.660	GACMD 2	99.030	GACMD 3	-126.898	GACMD 4	-77.050	GACMD 5	11.670	GACMD 6	-15.730
RHSANG 1	-52.660	RHSANG 2	99.030	RHSANG 3	-126.898	RHSANG 4	-77.050	RHSANG 5	11.670	RHSANG 6	-15.730
RRCMD 1	0.000	RRCMD 2	0.000	RRCMD 3	0.000	XRCMD 1	0.000	XRCMD 2	0.000	XRCMD 3	0.000
ROT 1	0.000	ROT 2	0.000	ROT 3	0.000	TRANS 1	0.000	TRANS 2	0.000	TRANS 3	0.000
PORARM 1	209.152	PORARM 2	-.787	PORARM 3	92.920	VEEPOR 1	-1.720	VEEPOR 2	0.000	VEEPOR 3	0.920
PRTOEE11	1.000	PRTOEE12	0.000	PRTOEE13	0.000	PRTOEE21	0.000	PRTOEE22	1.000	PRTOEE23	0.009
PRTOEE31	0.000	PRTOEE32	-.009	PRTOEE33	1.000	DIST	0.028	PHI	0.000		
RRSEL 1	0.000	RRSEL 2	0.000	RRSEL 3	0.000	XLRSEL 1	0.000	XLRSEL 2	0.000	XLRSEL 3	0.000
XLTIME	0.000	ROTIME	0.000								

TIME= 10.00 SECONDS

POSDES 1	-1107.000	POSDES 2	25.000	POSDES 3	-566.000	ATTDES 1	270.000	ATTDES 2	0.000	ATTDES 3	270.000
PORPOS 1	-909.342	PORPOS 2	23.002	PORPOS 3	-564.151	PORATT 1	269.993	PORATT 2	0.112	PORATT 3	270.011
GRCMD 1	-1.530	GRCMD 2	2.290	GRCMD 3	-2.663	GRCMD 4	-.053	GRCMD 5	-.312	GRCMD 6	-1.565
RHANGD 1	1.530	RHANGD 2	-2.290	RHANGD 3	2.663	RHANGD 4	0.053	RHANGD 5	0.312	RHANGD 6	-1.565
GACMD 1	-52.660	GACMD 2	99.030	GACMD 3	-126.898	GACMD 4	-77.850	GACMD 5	11.670	GACMD 6	-15.730
RHSANG 1	-34.077	RHSANG 2	80.378	RHSANG 3	-107.897	RHSANG 4	-73.776	RHSANG 5	16.123	RHSANG 6	-34.204
RRCMD 1	0.000	RRCMD 2	0.000	RRCMD 3	0.000	XRCMD 1	2.000	XRCMD 2	0.019	XRCMD 3	0.019
ROT 1	0.000	ROT 2	0.000	ROT 3	0.000	TRANS 1	1.640	TRANS 2	-1.145	TRANS 3	0.011
PORARM 1	201.999	PORARM 2	-1.113	PORARM 3	91.039	VEEPOR 1	-1.720	VEEPOR 2	0.000	VEEPOR 3	0.920
PRTOEE11	1.000	PRTOEE12	0.000	PRTOEE13	0.000	PRTOEE21	0.000	PRTOEE22	1.000	PRTOEE23	0.009
PRTOEE31	0.000	PRTOEE32	-.009	PRTOEE33	1.000	DIST	197.676	PHI	0.000		
RRSEL 1	0.018	RRSEL 2	0.066	RRSEL 3	3.421	XLRSEL 1	-1.102	XLRSEL 2	0.014	XLRSEL 3	0.041
XLTIME	0.236	ROTIME	0.000								

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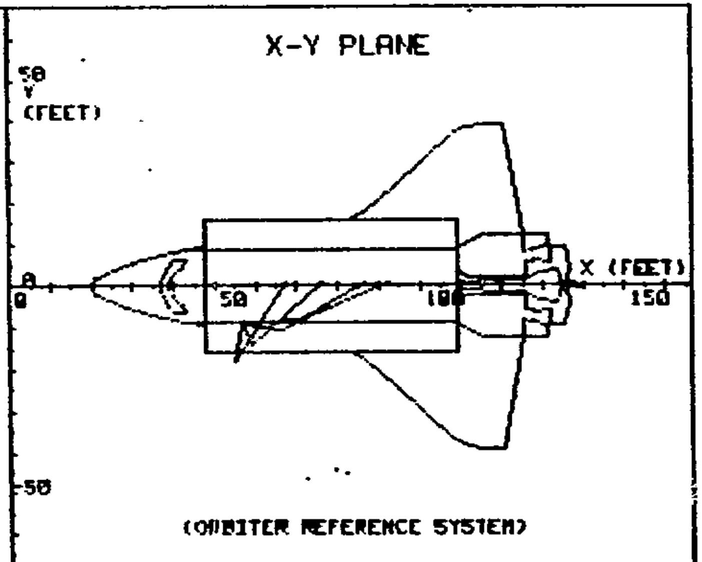
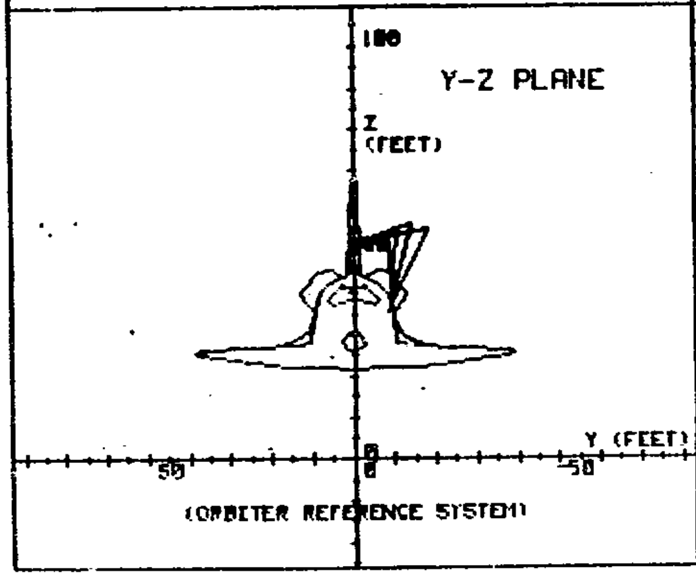
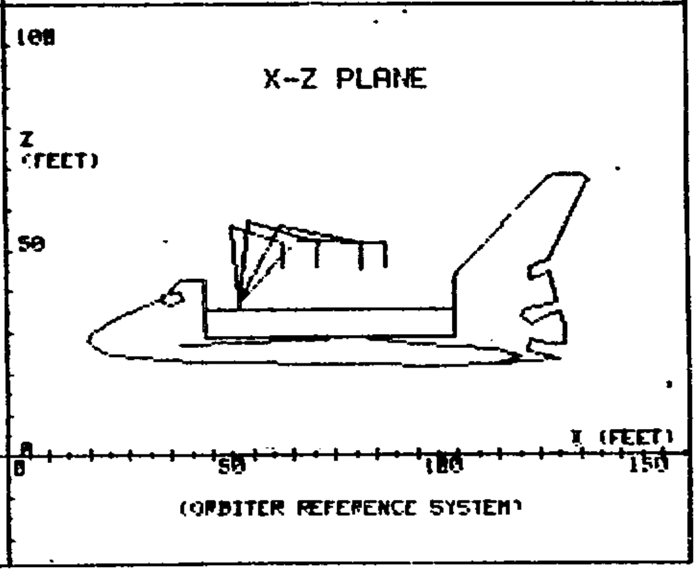
RMSKAT SAMPLE OUTPUT

ROCKWELL INTERNATIONAL PDRS
STS-2 MISSION (WO PAYLOAD)
PREPROGRAMMED AUTO MODE

	INIT	FINAL	UNIT
TIME	0.00	30.00	SEC
SY	-52.66	-21.35	DEG
SP	88.83	49.27	DEG
EP	-126.65	-53.37	DEG
WP	-77.85	-87.28	DEG
WY	11.67	10.10	DEG
WR	-15.73	-47.46	DEG
XC	-1107.00	-1107.00	IN
YC	25.00	25.00	IN
ZC	-566.00	-566.00	IN
X	-808.99	-1107.28	IN
Y	25.00	25.00	IN
Z	-363.58	-366.02	IN







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SOC ASSEMBLY -- END EFFECTOR LOCATIONS
ALTERNATIVE SCENARIO NO. 1

FLIGHT NO.	PAY-LOAD	INITIAL RMS END EFFECTOR COORDINATES						FINAL RMS END EFFECTOR COORDINATES					
					WRIST ATTITUDE						WRIST ATTITUDE		
		Xo	Yo	Zo	P	Y	R	Xo	Yo	Zo	P	Y	R
1	SM-1	1053	129.06	568.88	270	90	329	671.00	0	755.00	0	0	0
2	SM-2	1035	129.06	568.88	270	90	329	963.00	0	627.00	270	0	270
3	HM-1	1062	99.92	586.39	270	90	329	950.00	-84.00	857.00	0	90	0
4	HM-2	1062	99.92	586.39	270	90	329	950.00	-84.00	857.00	0	90	0
5A	LM	1186.5	99.92	586.39	270	90	329	852.50	155.00	802.64	0	90	0
5B	TM	750	0	400.00	180	180	0	679.50	-407.00	827.64	90	0	90
5C	TM	750	0	400.00	180	180	0	679.50	-407.00	827.64	90	0	90
6	FSF	1002	129.06	568.88	270	90	329	983.00	0	773.00	0	90	0
DM INTERFACE		621.00	0	515.00									
HPA INTERFACE		679.50	239.00	520.64									

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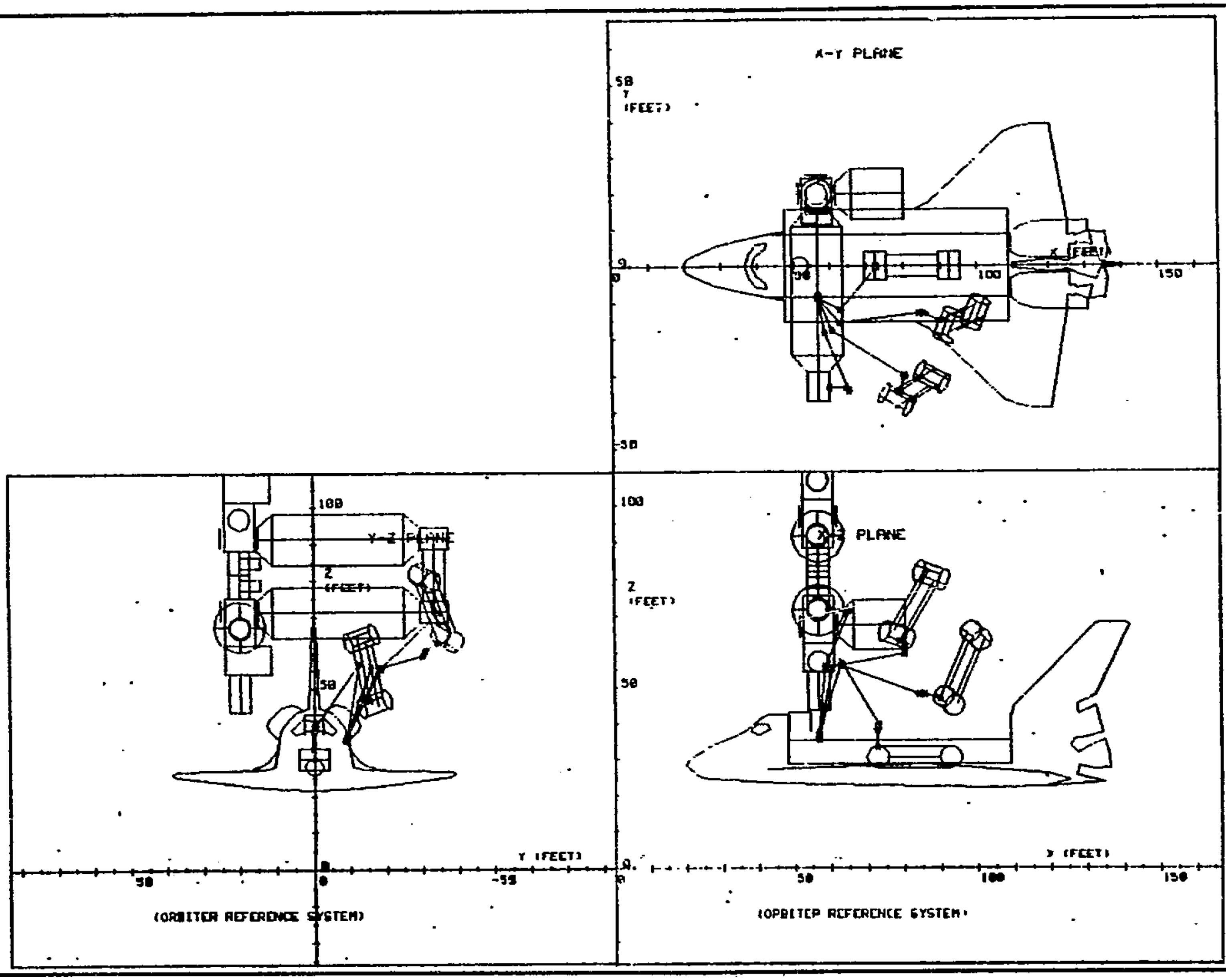
SOC TUNNEL ASSEMBLY



RMS ANGLES -- SOC ASSEMBLY

MODULE	SY (-177.4 TO 177.4)	SP (0.6 TO 142.4)	EP (-0.4 TO -157.6)	WP (-116.4 TO 116.4)	WY (-116.6 TO 116.6)	WR (-442 TO 442)
SM-1 STOWED	-31.54	50.71	-72.86	-11.92	-53.47	-28.52
↓	-46.68	68.02	-82.50	51.77	-61.30	17.48
	-61.82	85.34	-92.14	115.45	-69.13	63.48
SM-1 DEPLOYED	-76.97	102.65	-101.79	$\boxed{179.14}$	-76.97	109.48
SM-2 STOWED	-32.82	54.09	-78.37	-8.85	-52.40	152.65
SM-2 DEPLOYED	-32.59	76.54	-85.32	-92.01	16.32	-55.85
HM1 STOWED	-30.93	60.48	-82.34	-12.68	-53.97	-29.10
HM1 DEPLOYED	-21.64	78.56	-42.91	-79.48	-61.20	140.00
HM2 = HM1						
LM STOWED	-28.62	53.82	-72.01	-18.26	-55.85	148.57
LM DEPLOYED	-61.31	75.58	-68.93	-28.61	-26.91	169.66
TM STOWED	-28.99	71.21	-133.56	-37.38	-16.96	120.45
↓	0.54	75.00	-97.30	15.80	30.20	56.70
	27.91	78.80	-61.10	69.10	43.30	6.90
TM DEPLOYED	56.36	82.58	-24.99	$\boxed{122.41}$	56.36	-70.52

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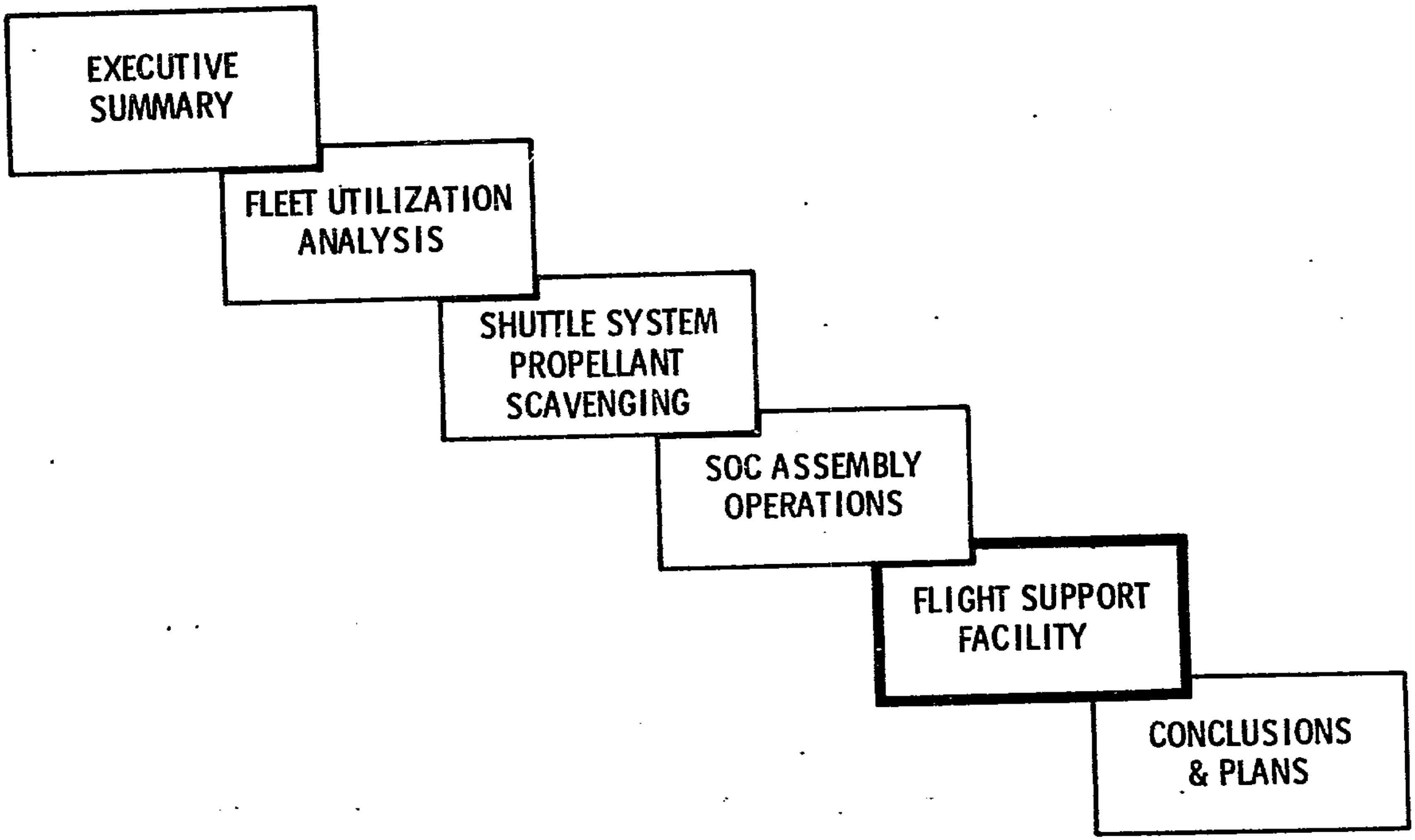
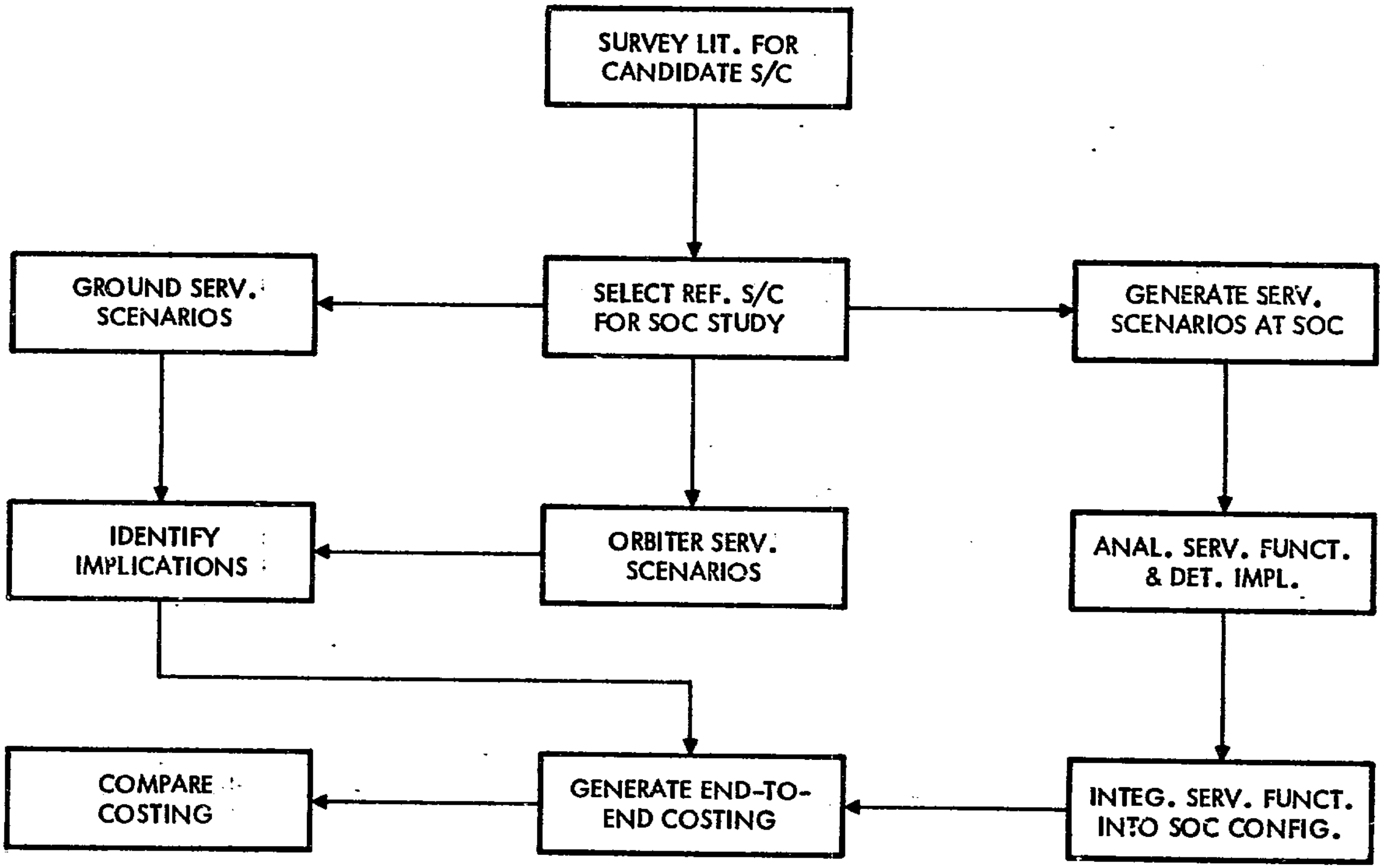

EXECUTIVE SUMMARY
FLEET UTILIZATION ANALYSIS
SHUTTLE SYSTEM PROPELLANT SCAVENGING
SOC ASSEMBLY OPERATIONS
FLIGHT SUPPORT FACILITY
CONCLUSIONS & PLANS

TASK 4 -- FLIGHT SUPPORT FACILITY
OBJECTIVES

COMPARE SERVICING/CHECKOUT LOGIC & COSTS OF SERVICING FREE FLYERS AT THE SOC FLIGHT SUPPORT FACILITY (FSF), ON THE GROUND & FROM THE ORBITER

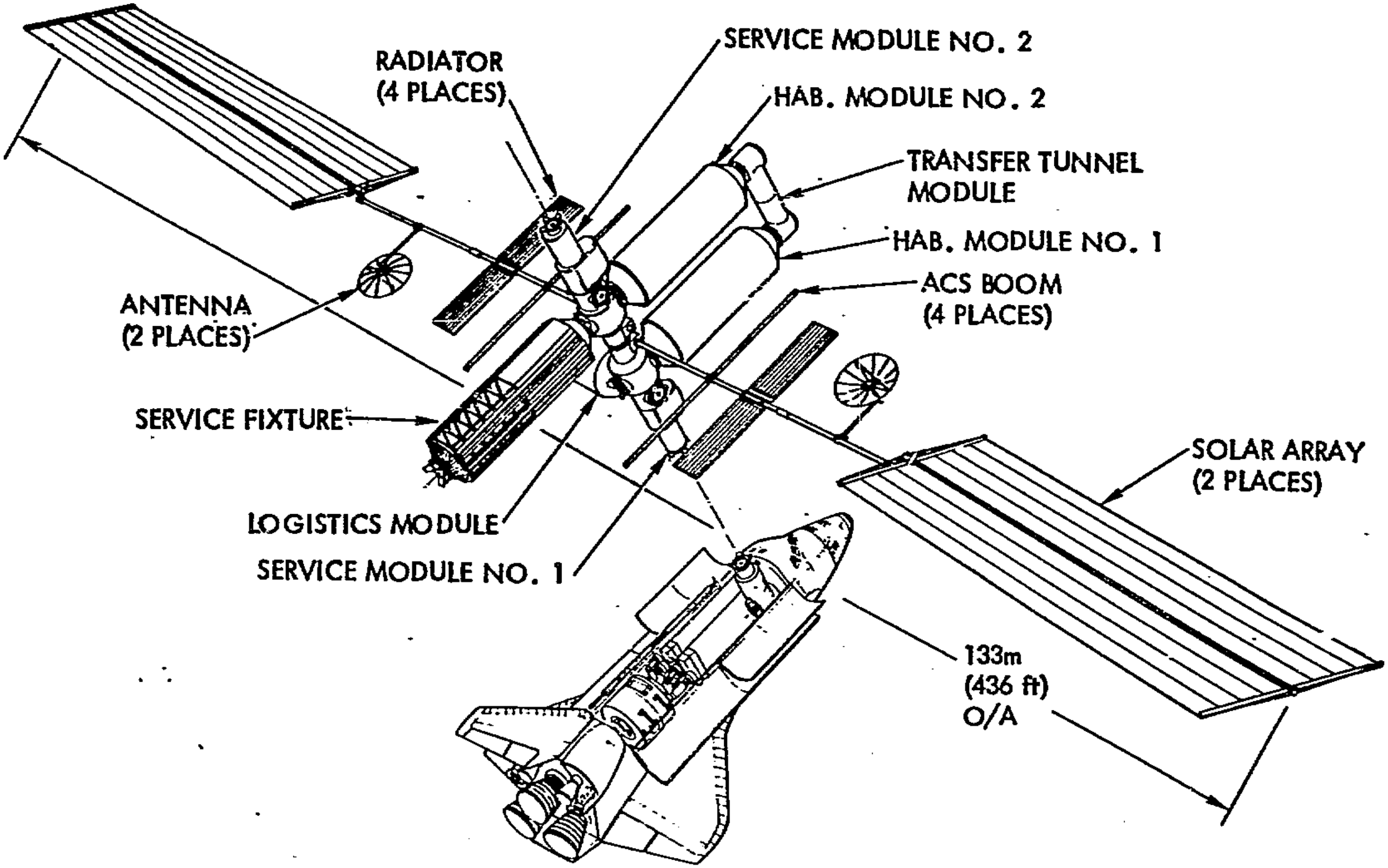
TASK 4 -- FLIGHT SUPPORT FACILITY



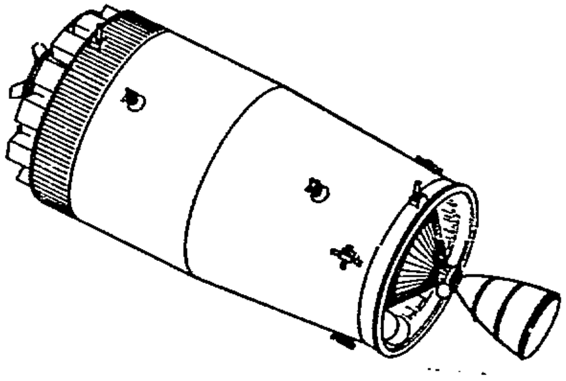
ACCOMPLISHMENTS TO DATE

- UPDATED SOC REFERENCE CONFIGURATION
- SELECTED THREE REPRESENTATIVE SPACECRAFTS FOR SERVICING & COST ESTIMATES
  - SINGLE STAGE OTV
  - GEO COMMUNICATION SATELLITE
  - SPACE PROCESSING FACILITY (FREE FLYER)
- GENERATED SERVICING SCENARIOS
- COMPLETED SERVICING SCENARIO ANALYSIS & DETERMINED IMPLICATIONS
- COMPLETED MANPOWER ESTIMATES FOR SERVICING SCENARIOS

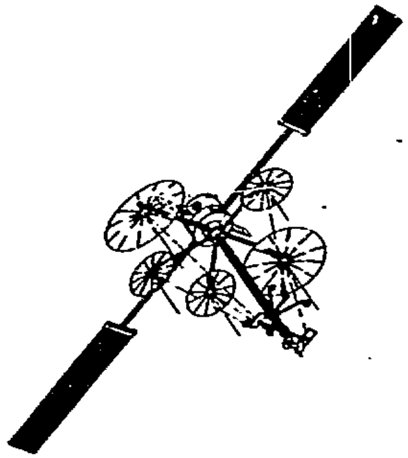
SPACE OPERATIONS CENTER (SOC)



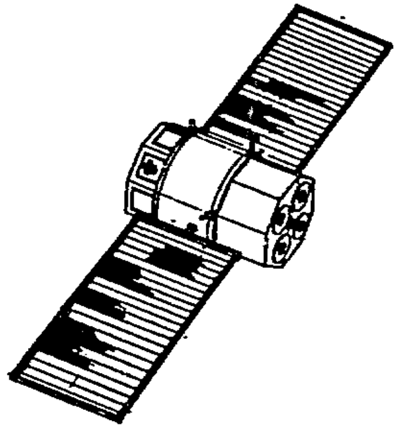
REPRESENTATIVE SPACECRAFTS



OTV



COMMUNICATION SATELLITE



SPACE PROCESSING FACILITY

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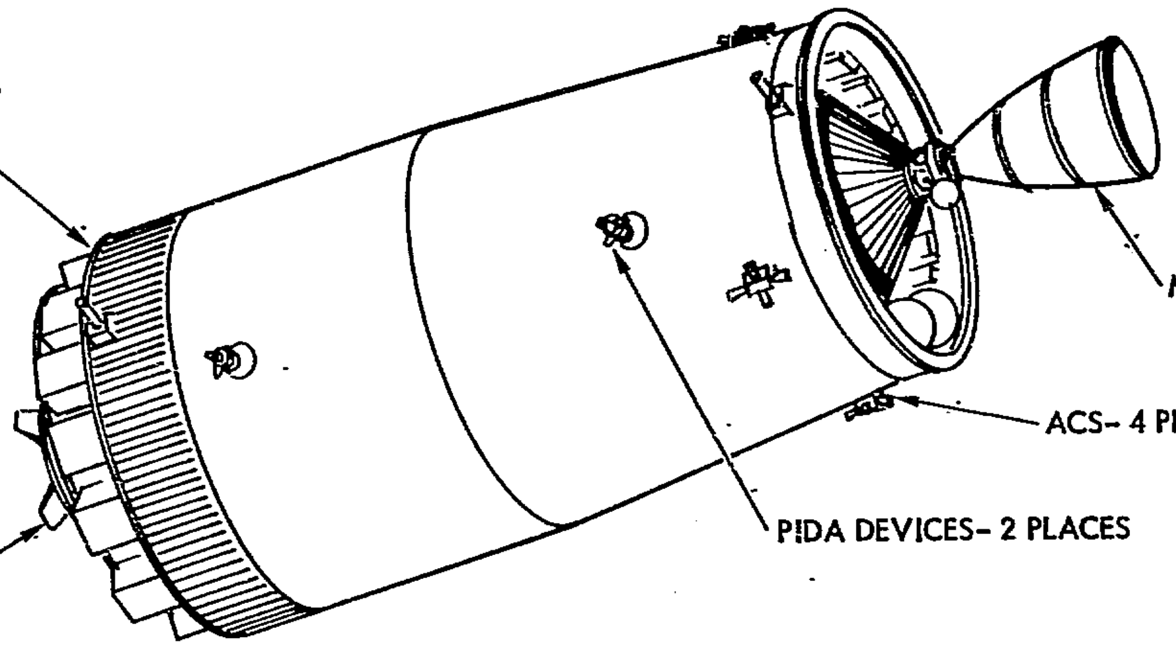
- FEATURES SIGNIFICANT TO SERVICING
  - LOADING OF FLUIDS
    - CRYOGENICS - LO_2, LH_2
    - NON-CRYOGENICS - He, GN_2, HYDRAZINE
  - MODULE & COMPONENT EXCHANGE OPS
  - EXTENSIVE DEPLOYMENT & C/O OPS
  - FREQUENT REVISITS
  - SMALL TO LARGE S/C

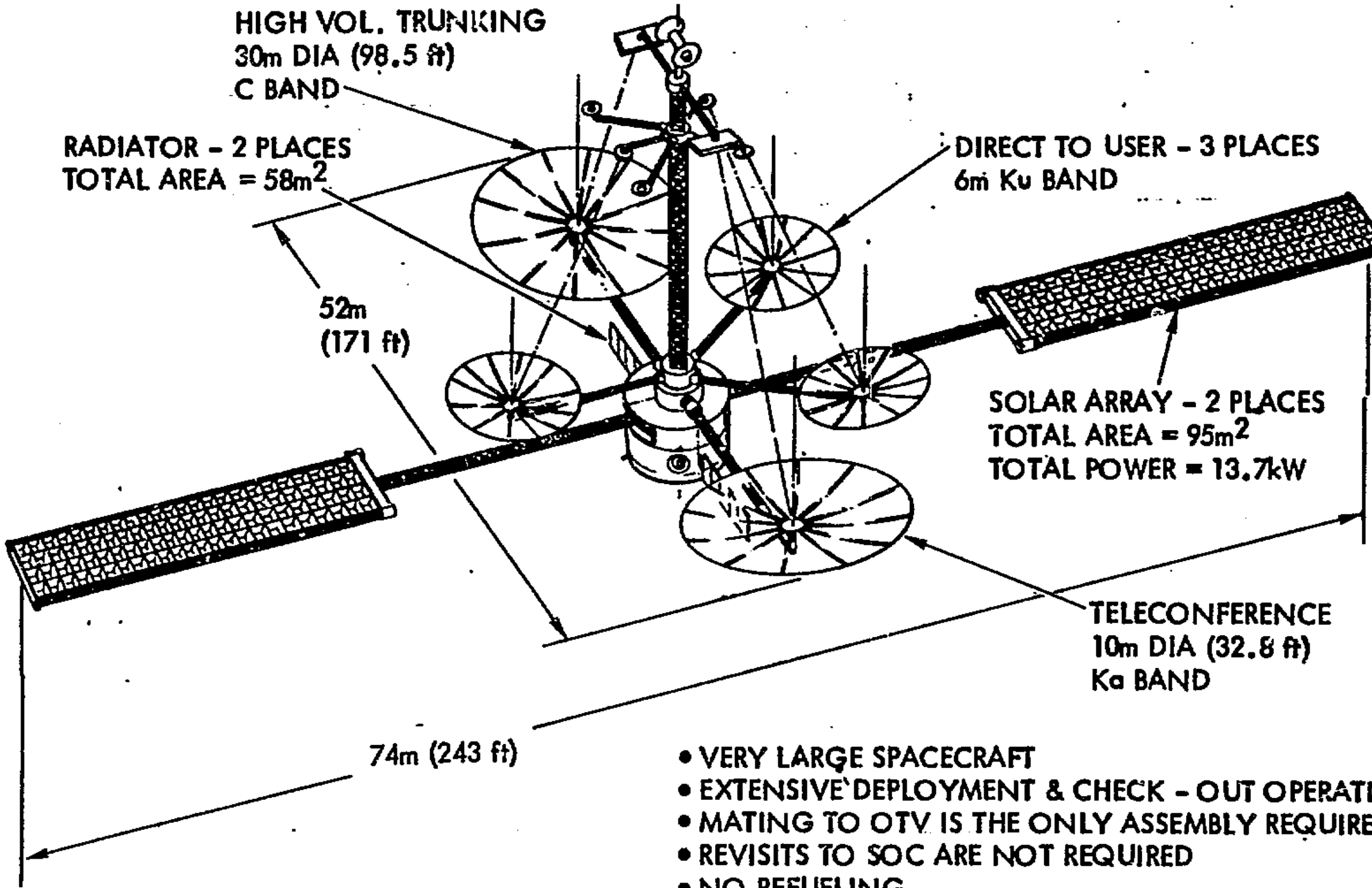
S/C	GROUND SERVICING	ORBITER SERVICING	SOC SERVICING
OTV	✓	N/A	✓
COMM SAT	N/A	✓ INITIAL ASSY & LAUNCH TO GEO	✓ INITIAL ASSY & LAUNCH TO GEO
SPACE PROCESSING FACILITY	N/A	✓	✓

ORBIT TRANSFER VEHICLE (OTV)



- REFUELING OF A SPECTRUM OF PROPELLANTS- LO_2/LH_2; HYDRAZINE; He & GN_2
- EXTENSIVE SERVICING & MODULE EXCHANGE OPERATIONS ARE REQUIRED
- FREQUENT VISITS TO SOC

GEOSYNCHRONOUS COMMUNICATIONS SPACECRAFT -- CONFIGURATION NO. 1



- VERY LARGE SPACECRAFT
- EXTENSIVE DEPLOYMENT & CHECK - OUT OPERATIONS
- MATING TO OTV IS THE ONLY ASSEMBLY REQUIRED
- REVISITS TO SOC ARE NOT REQUIRED
- NO REFUELING

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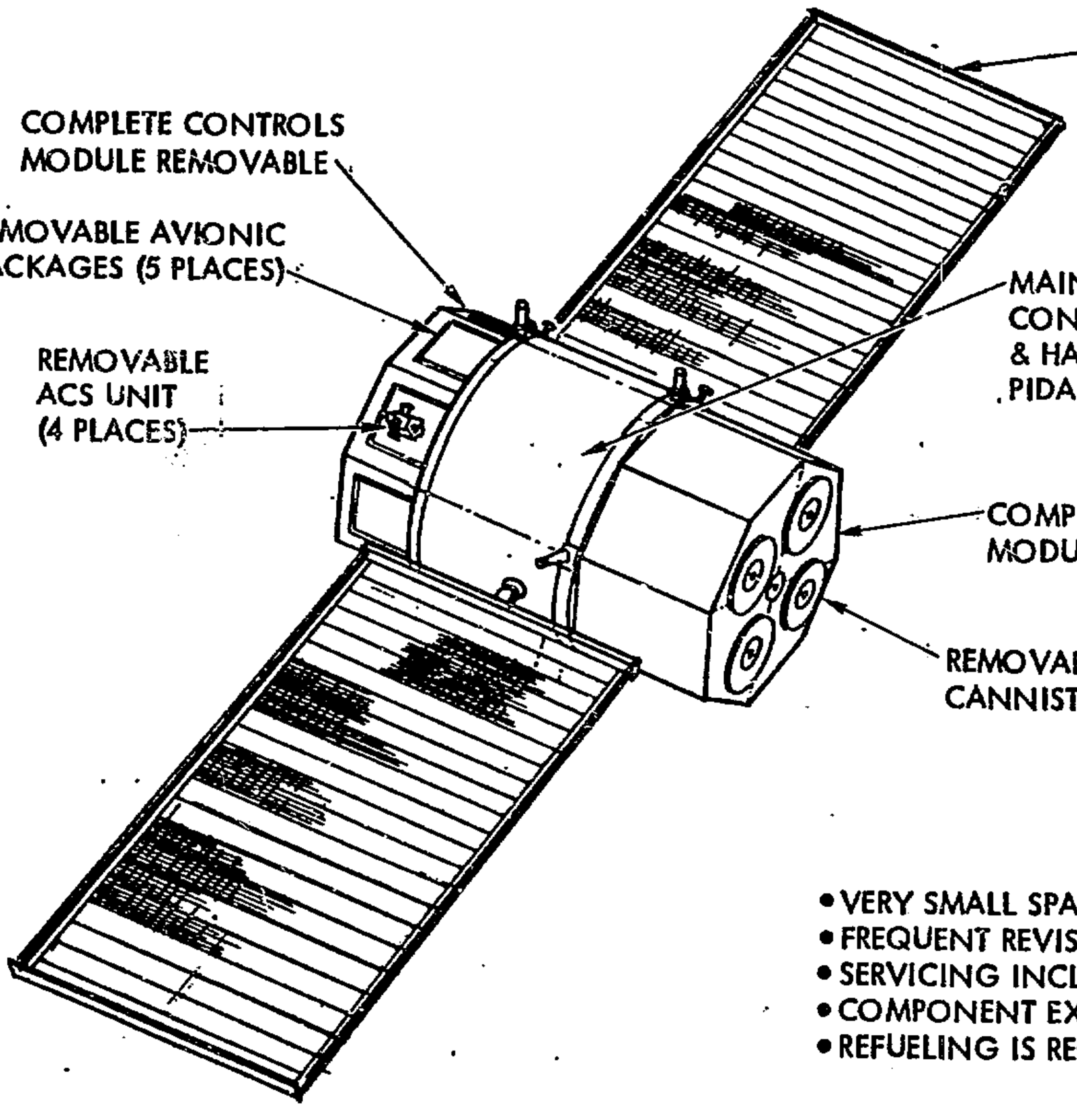
SPACE PROCESSING FACILITY (SPF)



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- VERY SMALL SPACECRAFT
- FREQUENT REVISITS TO SOC
- SERVICING INCLUDE MODULE &
- COMPONENT EXCHANGE OPERATIONS
- REFUELING IS REQUIRED

ORBITER
BASIC GROUNDRULES AND ASSUMPTIONS

- TRANSPORTATION VEHICLE IS STD STS
- SERVICING TO BE CONDUCTED WITHIN ORBITER OPERATIONAL & SAFETY CONSTRAINTS
- REMOTE SERVICING OPERATIONS CAPABILITY WITH EVA BACKUP
- CONTROL & DATA LINKS WITH S/C BEING SERVICED
- VOICE LINK WITH S/C OCC
- LOGISTICS & FUEL REPLENISHMENT PROVISIONS
  - UNAVAILABLE FOR COMMSAT & OTV
  - AVAILABLE FOR SPF
- RMS, DOCKING MODULE, HPA, PIDA, & FSS AVAILABLE AS ASE OPTIONS

SOC
BASIC GROUNDRULES AND ASSUMPTIONS

- CONFIGURATION PER SOC / SHUTTLE INTERACTION STUDY & AS UPDATED FOR EXTENSION STUDY

- SERVICING TO BE CONDUCTED WITHIN SOC OPERATIONAL & SAFETY CONSTRAINTS AT 28.5^{0} INCL & 200 NM ALTITUDE

- LOGISTICS & REFUELING PROVISIONS ON SOC

- CONTROL & DATA LINKS WITH S / C BEING SERVICED

- VOICE LINK WITH S / C OCC

- NON-PROPULSIVE VENT & PURGE PROVISIONS

GROUND BASED OTV
BASIC GROUNDRULES AND ASSUMPTIONS

- CONTROL & DATA LINK WITH ORBITER
- LAUNCHED IN FUELED CONDITION
- STRUCTURAL STRENGTH FOR FUELED LAUNCH
- PROVISION FOR HANDLING BY ORBITER
- HEALTH, STATUS & PERFORMANCE MONITORING PROVISIONS OF OTV & ITS SUBSYSTEMS
- NON-PROPULSIVE VENT & PURGE PROVISIONS
- SWITCHING CAPABILITY TO REDUNDANT SYSTEMS OR UNITS

SPACE BASED OTV
BASIC GROUNDRULES AND ASSUMPTIONS

- CONTROL & DATA LINKS WITH ORBITER & SOC
- MODULAR COMPONENT DESIGN TO FACILITATE ON ORBIT REPLACEMENT
- HEALTH, STATUS & PERFORMANCE MONITERING PROVISIONS OF OTV & ITS SUBSYSTEM
- LAUNCHED IN NON-FUELED CONDITIONS
- PROVISIONS FOR HANDLING BY SOC & ORBITER
- NON-PROPULSIVE VENT & PURGE PROVISIONS
- OTV RETURNS TO EARTH AFTER 8 MISSIONS FOR MAJOR GROUND OVERHAUL
- SINGLE STAGE -- UNMANNED OTV CONFIGURATIONS
- SWITCHING CAPABILITY TO REDUNDANT SYSTEMS OR UNITS

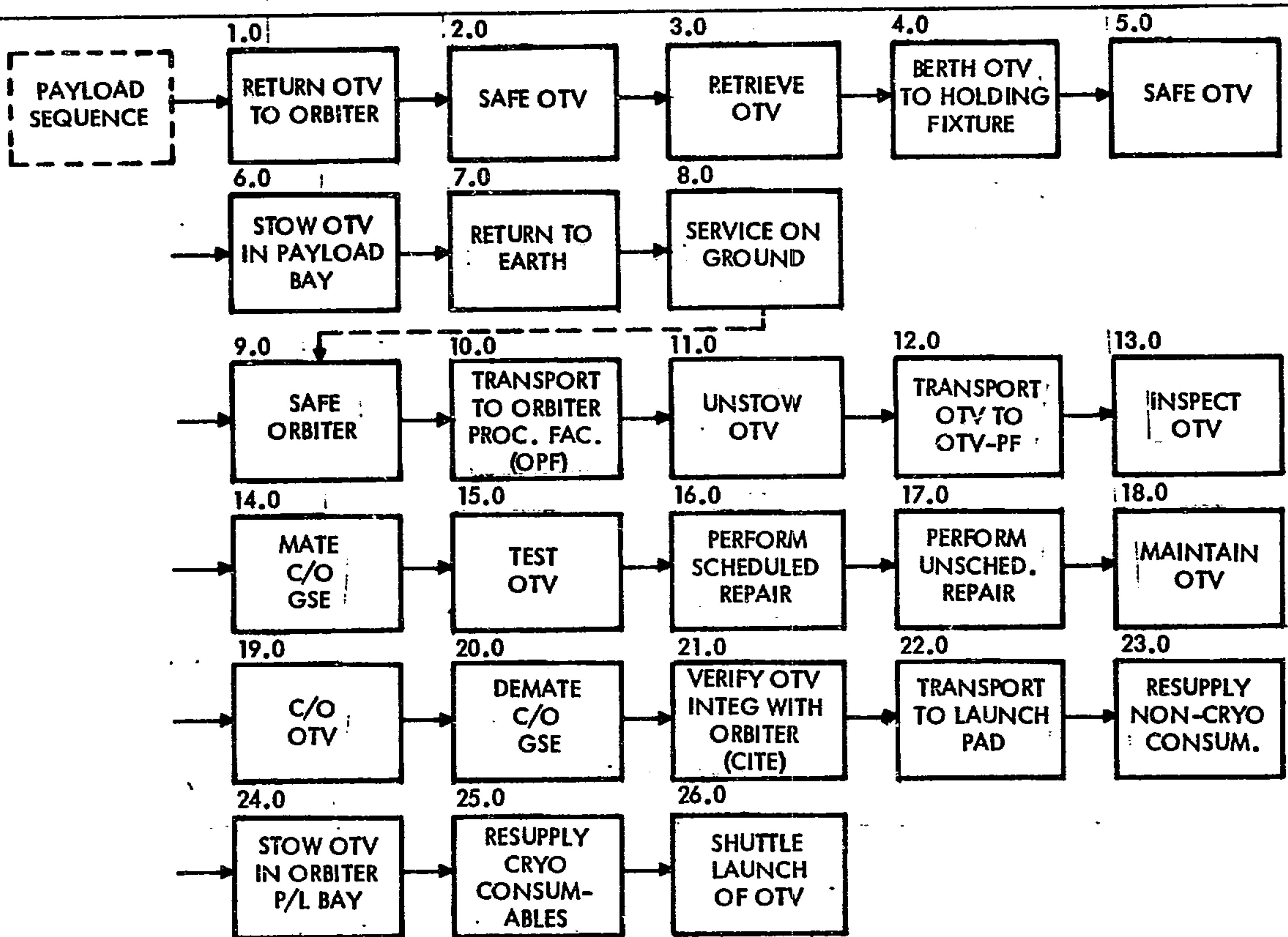
COMMSAT
BASIC GROUNDRULES AND ASSUMPTIONS

- LAUNCHED IN FUELED CONDITION
- CONTROL & DATA LINKS WITH SOC & ORBITER
- MANUAL OVERRIDE PROVISIONS FOR ALL MECHANISMS
- MODULAR COMPONENT DESIGN TO FACILITATE ON-ORBIT REPLACEMENT
- ACCESSIBILITY IS PRIME DESIGN REQUIREMENT
- HEALTH, STATUS & PERFORMANCE MONITERING PROVISIONS OF COMMSAT & ITS SUBSYSTEMS
- SWITCHING CAPABILITY TO REDUNDANT SYSTEMS OR UNITS

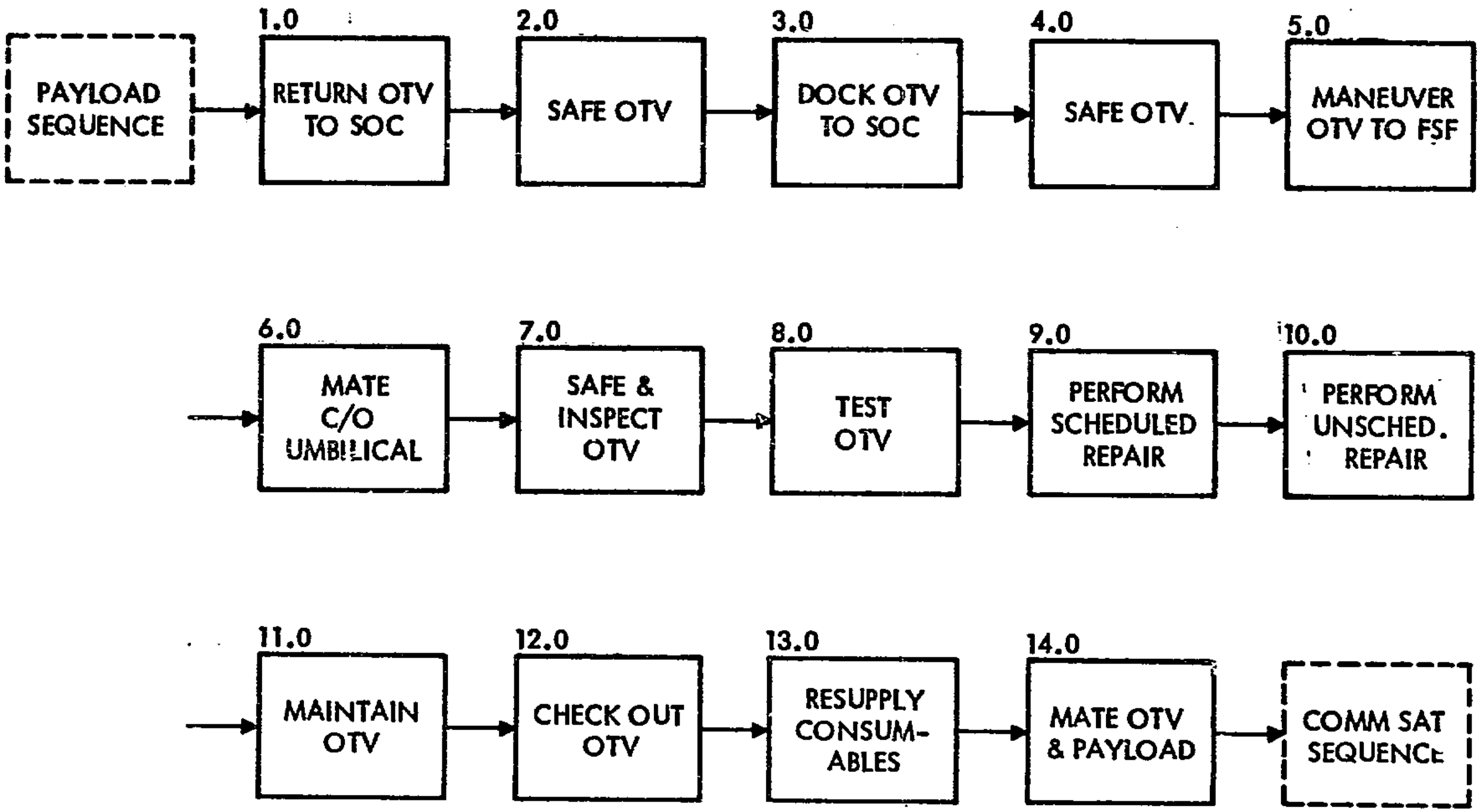
SPF
BASIC GROUNDRULES AND ASSUMPTIONS

- RETRACTABLE SOLAR ARRAYS
- CONTROL & DATA LINKS WITH ORBITER & SOC
- LAUNCHED IN FUELED CONDITION
- NON-PROPULSIVE VENT & PURGE PROVISIONS
- SWITCHING CAPABILITY TO REDUNDANT SYSTEMS OR UNITS
- MODULAR COMPONENT DESIGN TO FACILITATE ON-ORBIT REPLACEMENT

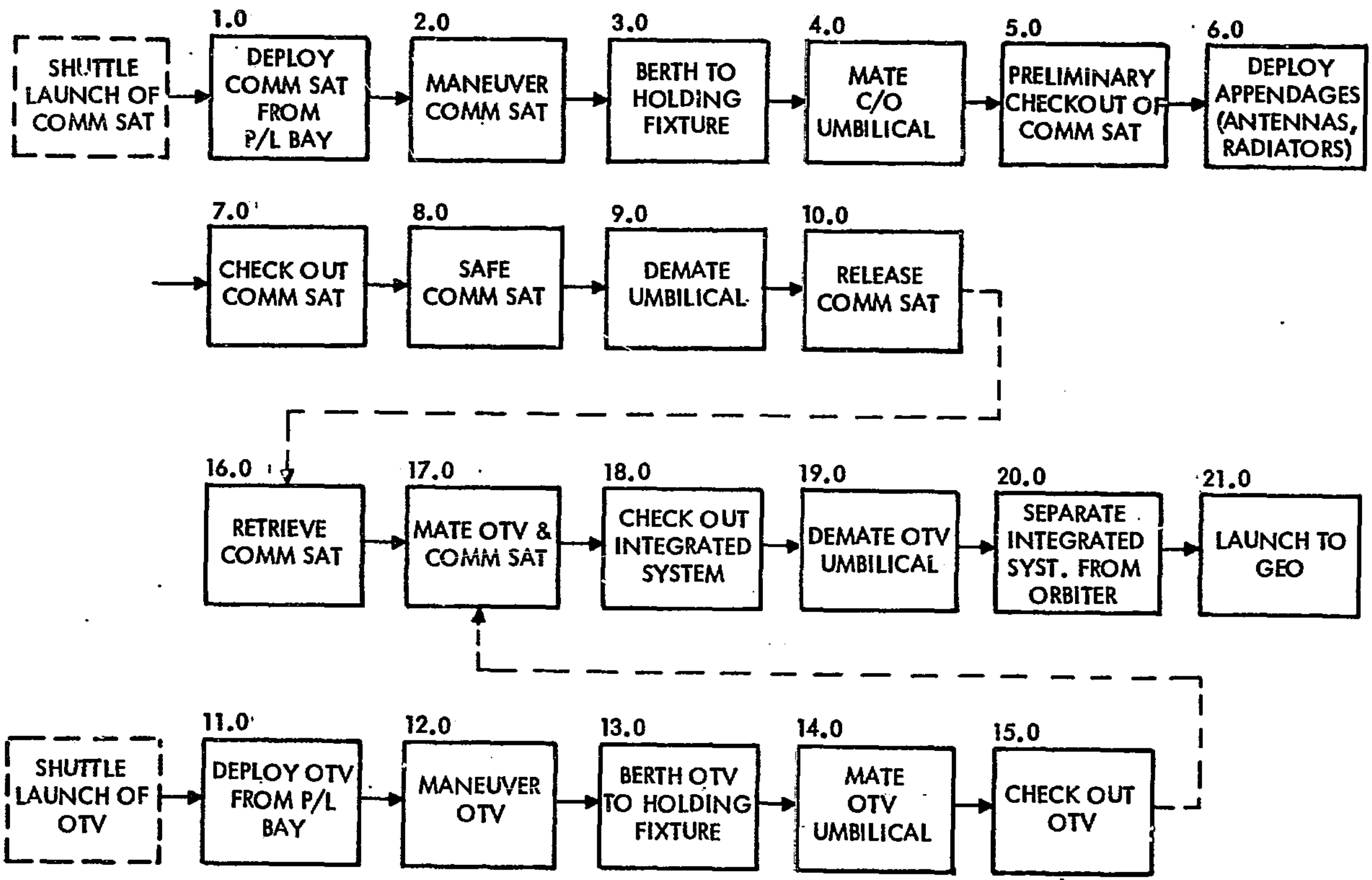
OTV -- GROUND SERVICING



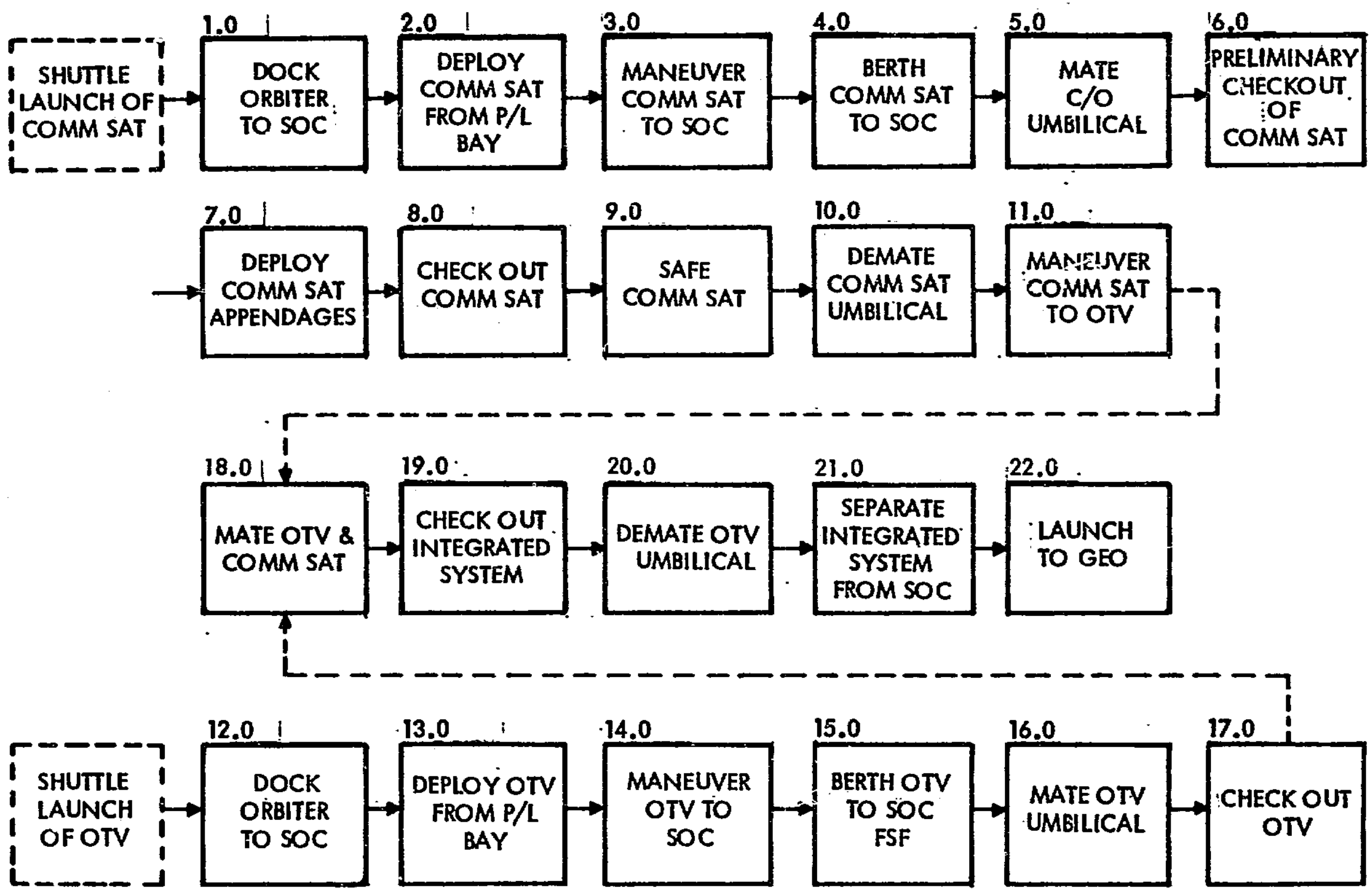
OTV -- SOC SERVICING



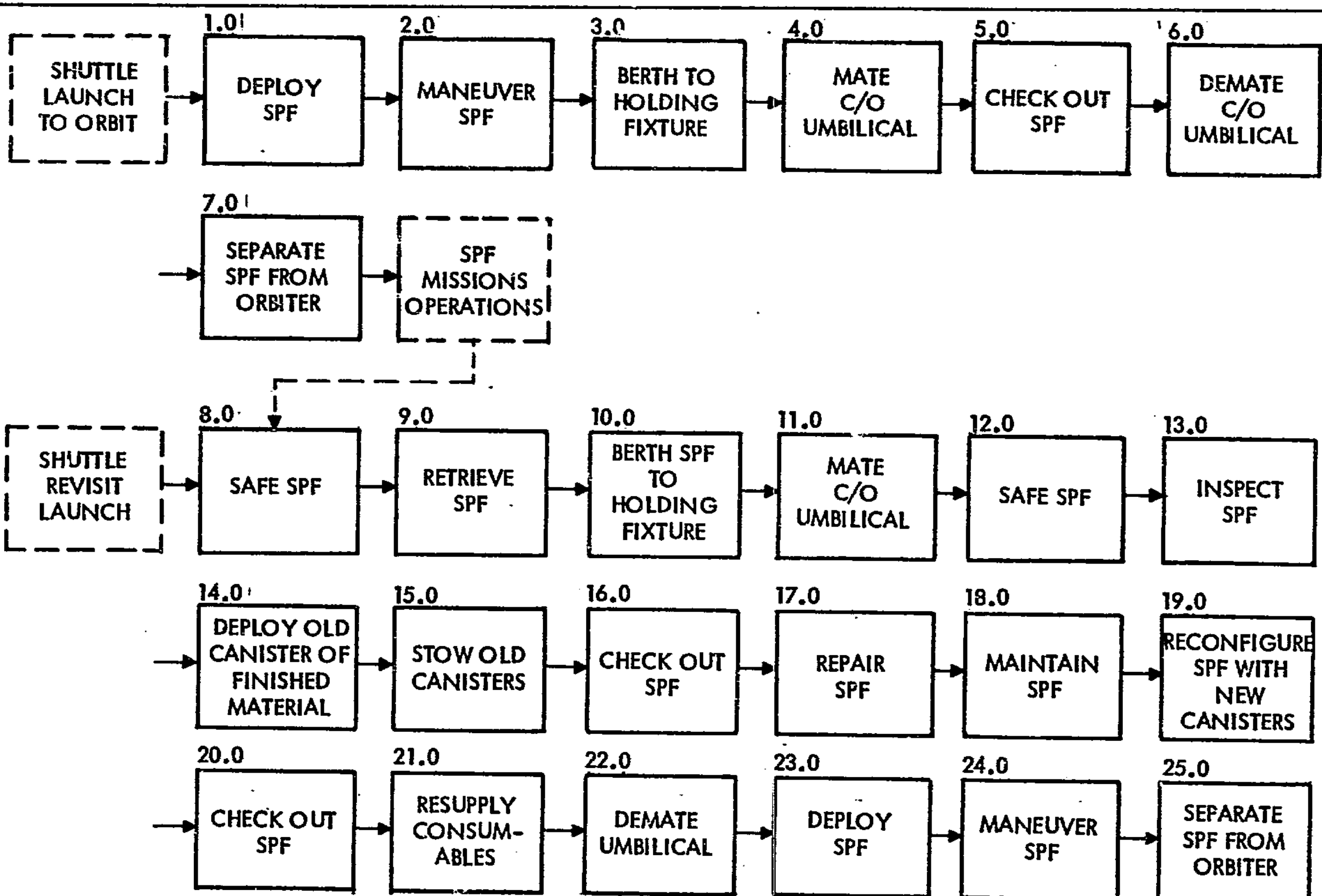
COMM SAT -- ORBITER SERVICING



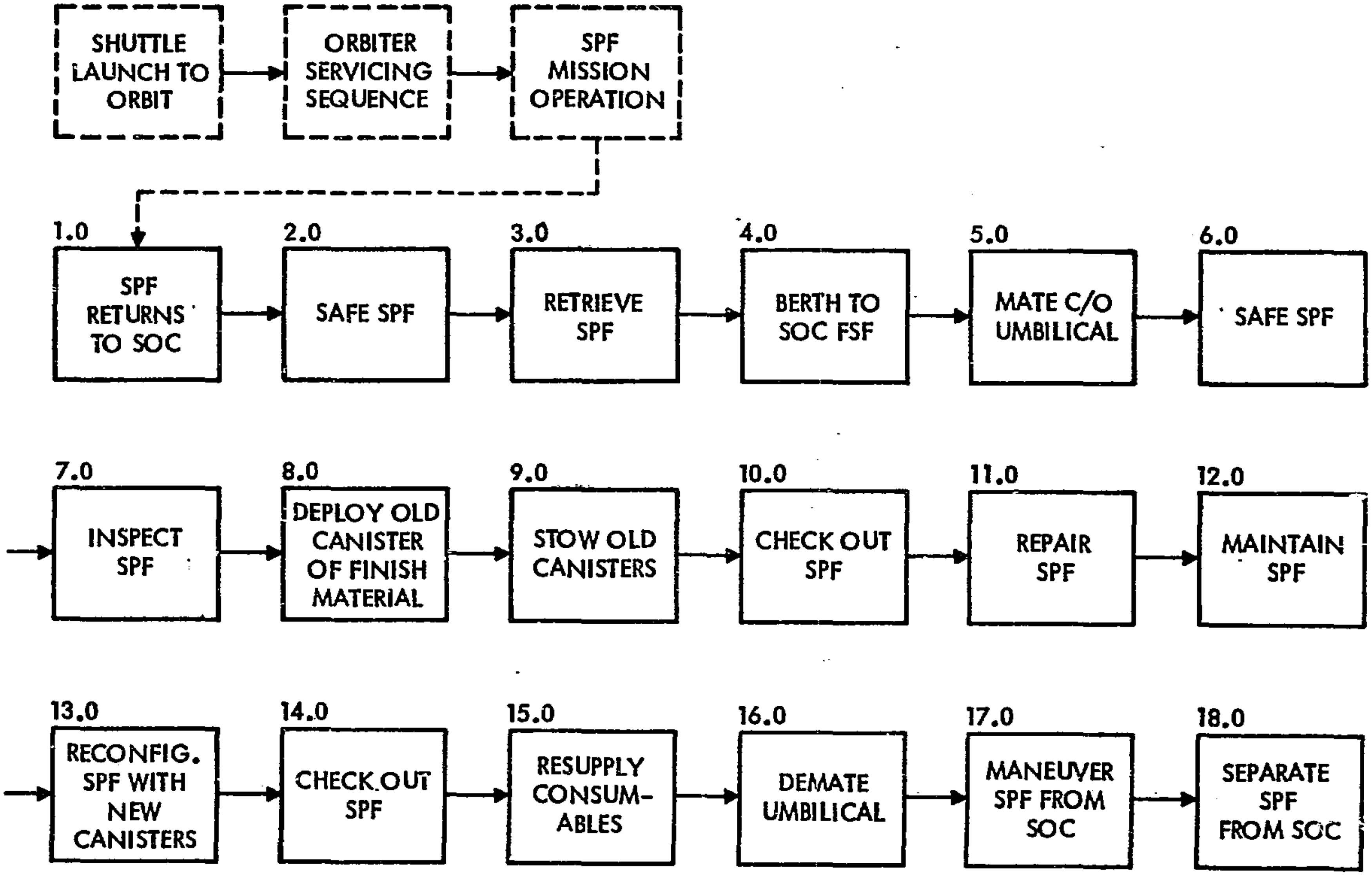
COMM SAT -- SOC SERVICING



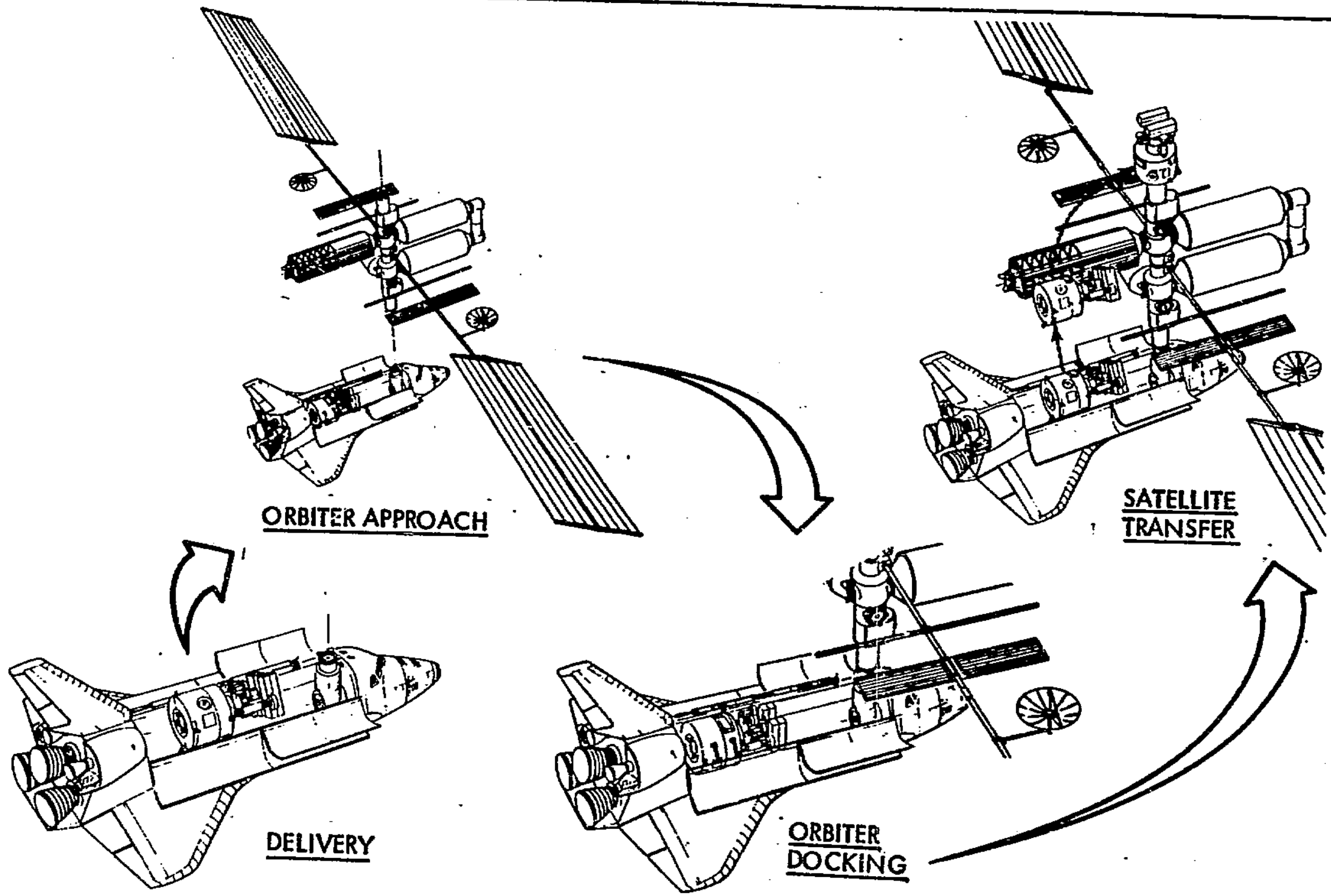
SPACE PROCESSING FACILITY -- ORBITER SERVICING



SPACE PROCESSING FACILITY -- SOC SERVICING



COMMSAT -- SOC SERVICING SCENARIO



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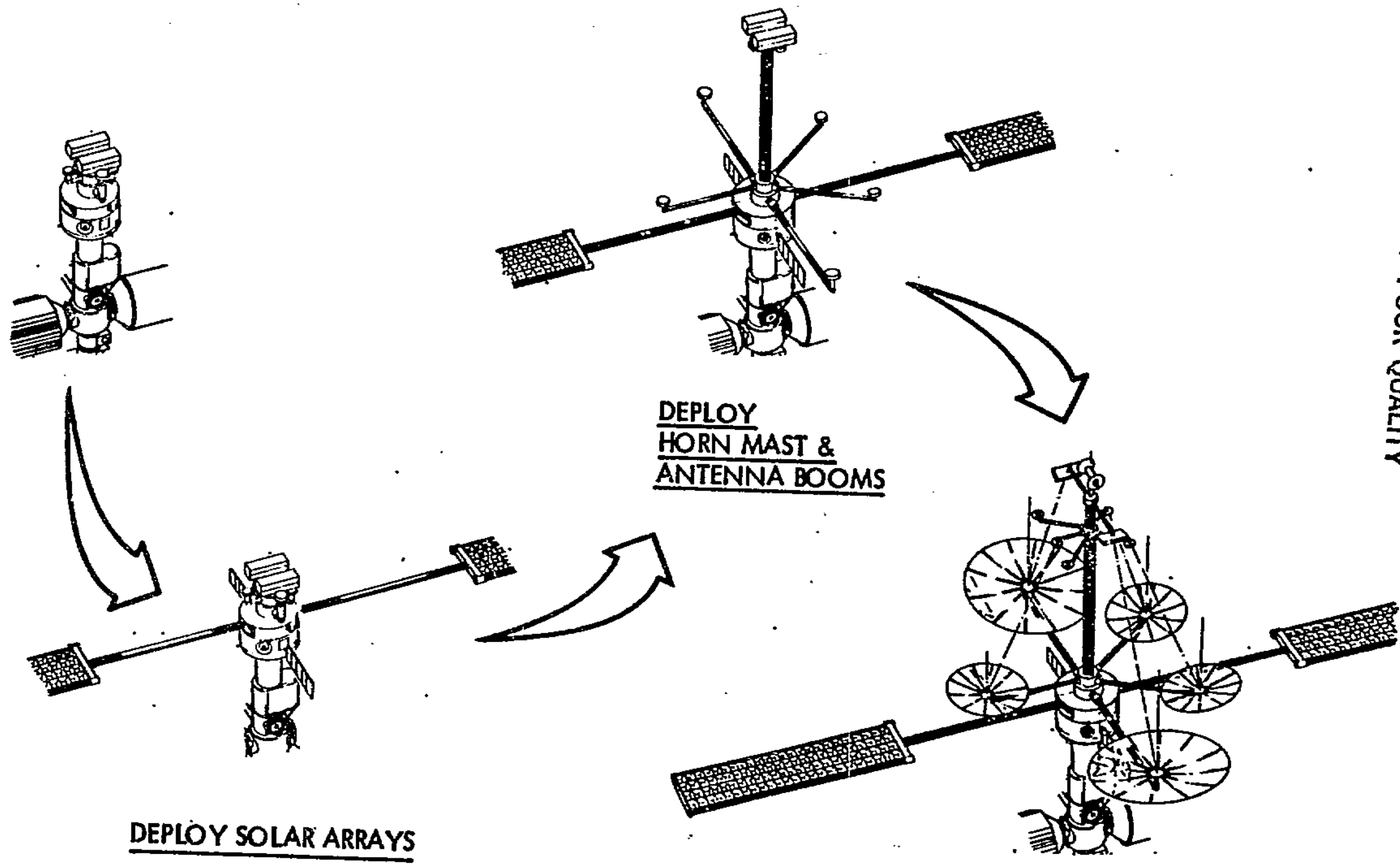
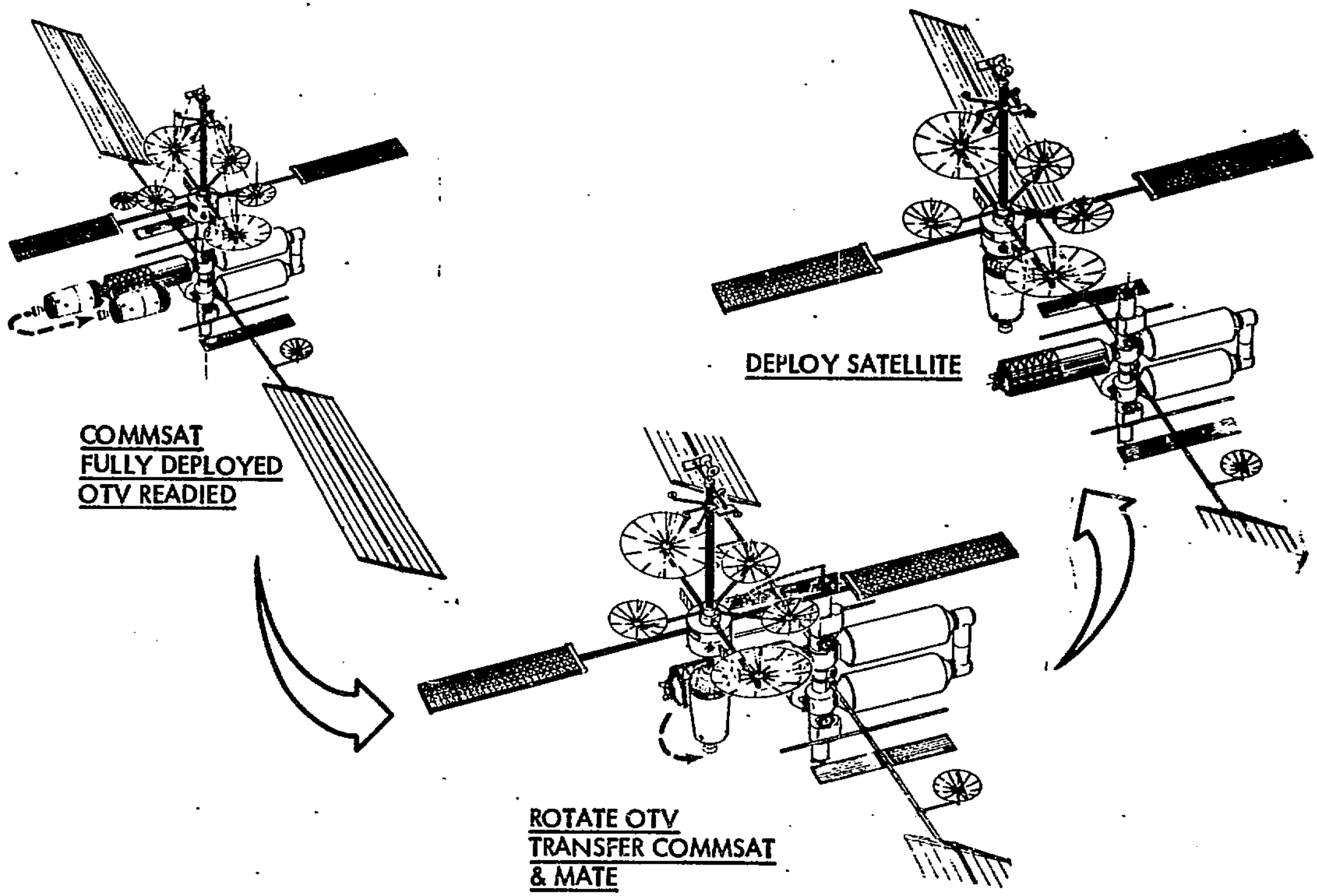
COMMSAT -- APPENDAGES DEPLOYMENT SCENARIO



COMMSAT/OTV MATING & DEPLOYMENT SCENARIO



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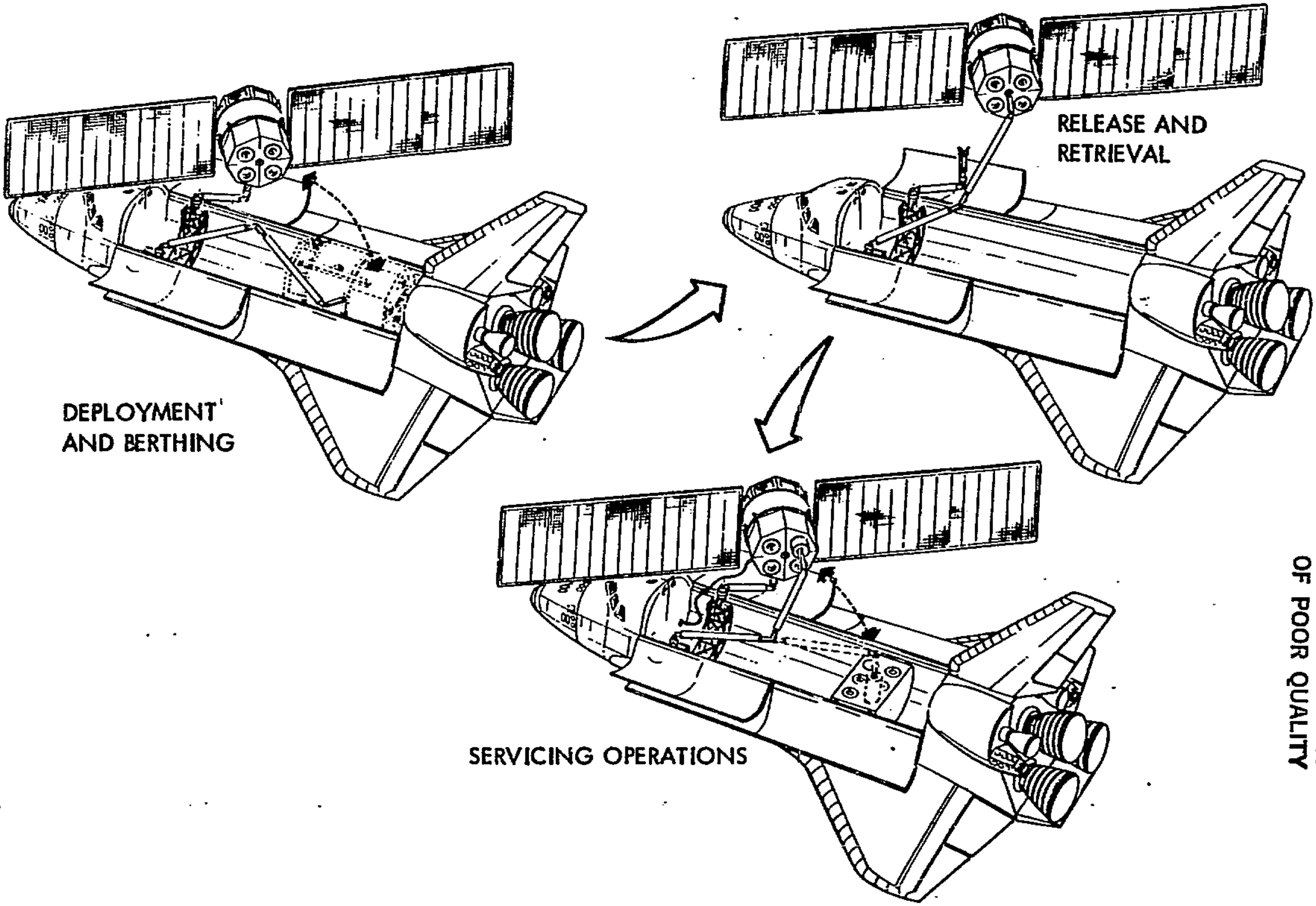
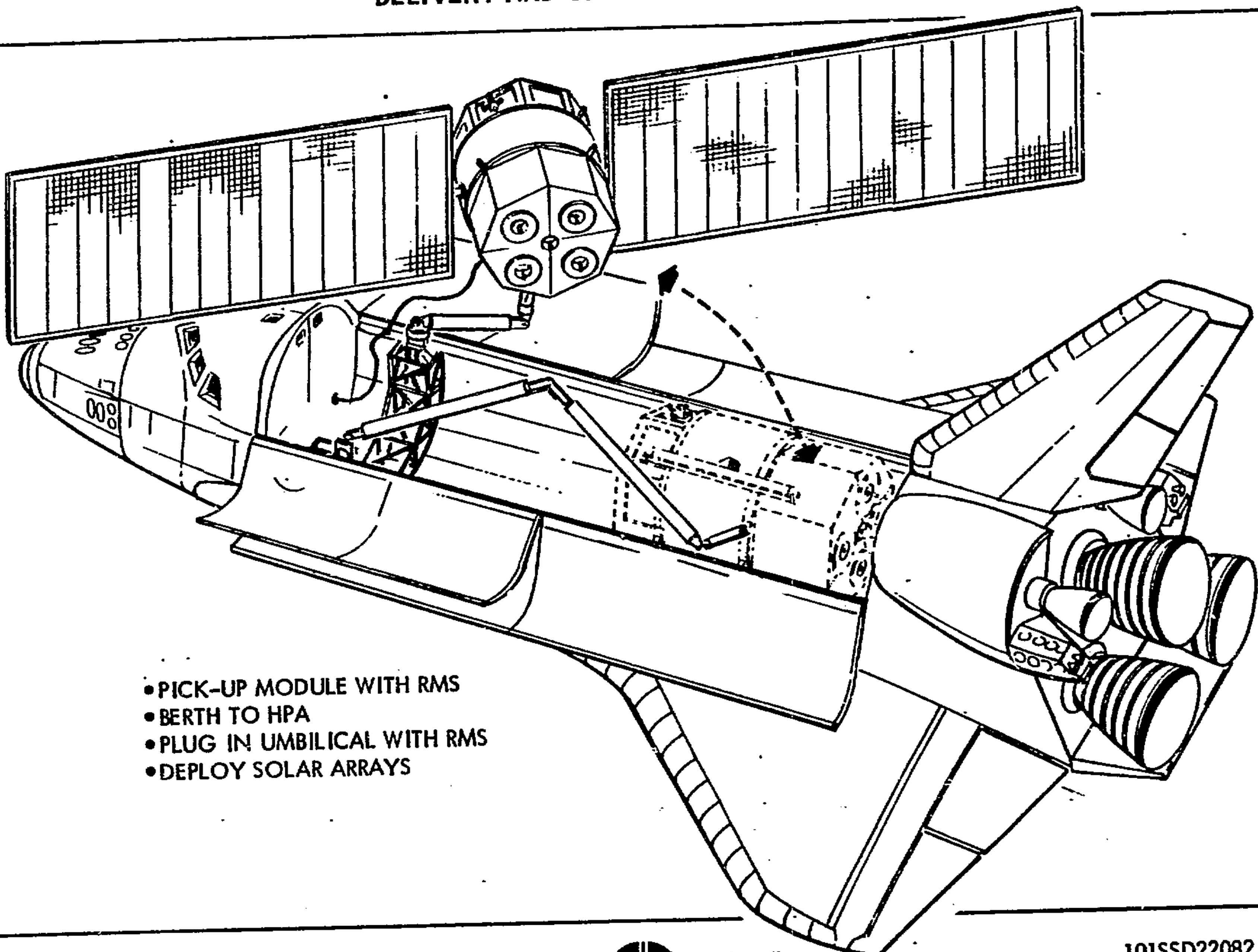
SPACE PROCESSING FACILITY
ORBITER SERVICING



SPACE PROCESSING FACILITY
DELIVERY AND CHECK-OUT BY ORBITER



- PICK-UP MODULE WITH RMS
- BERTH TO HPA
- PLUG IN UMBILICAL WITH RMS
- DEPLOY SOLAR ARRAYS

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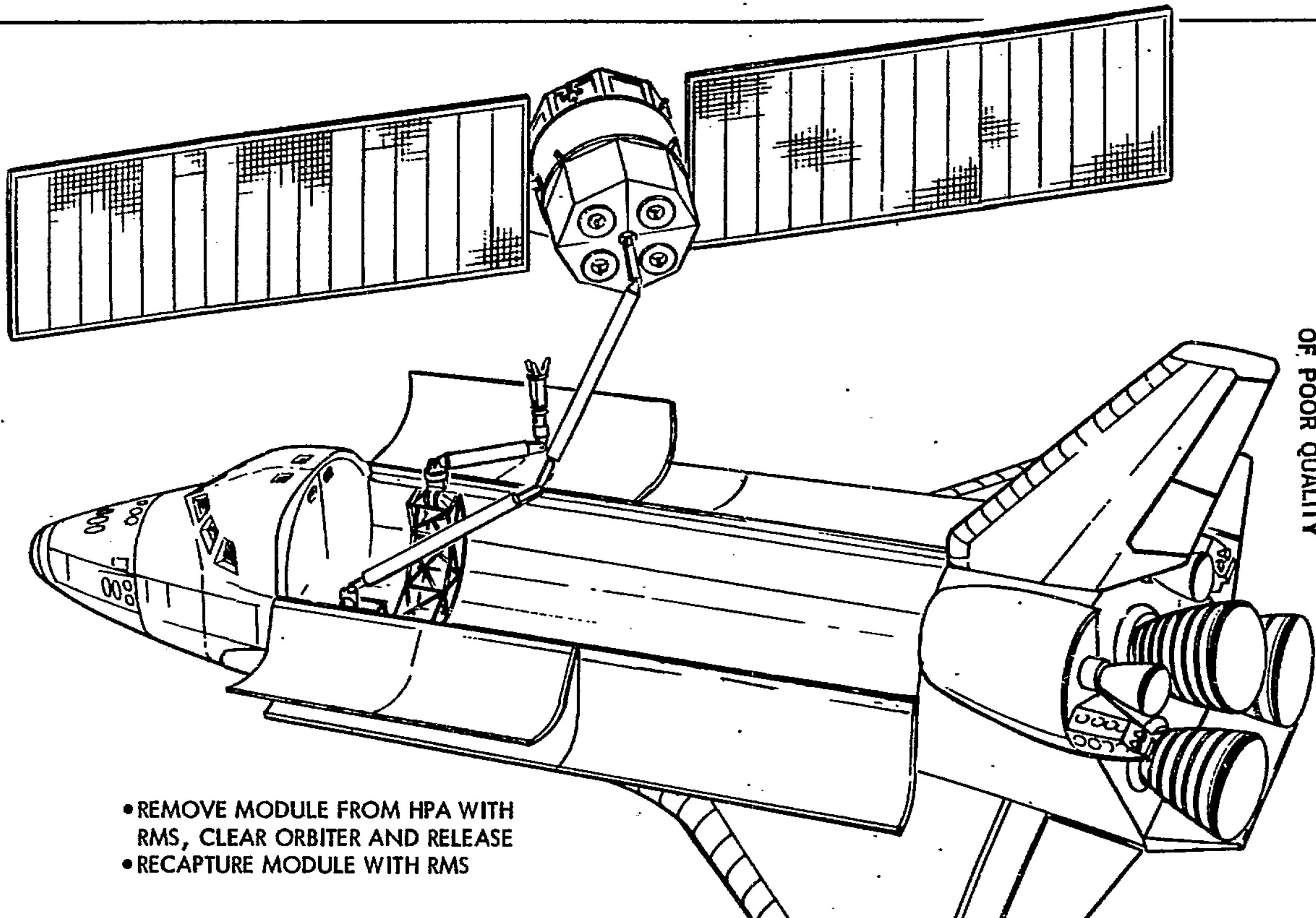
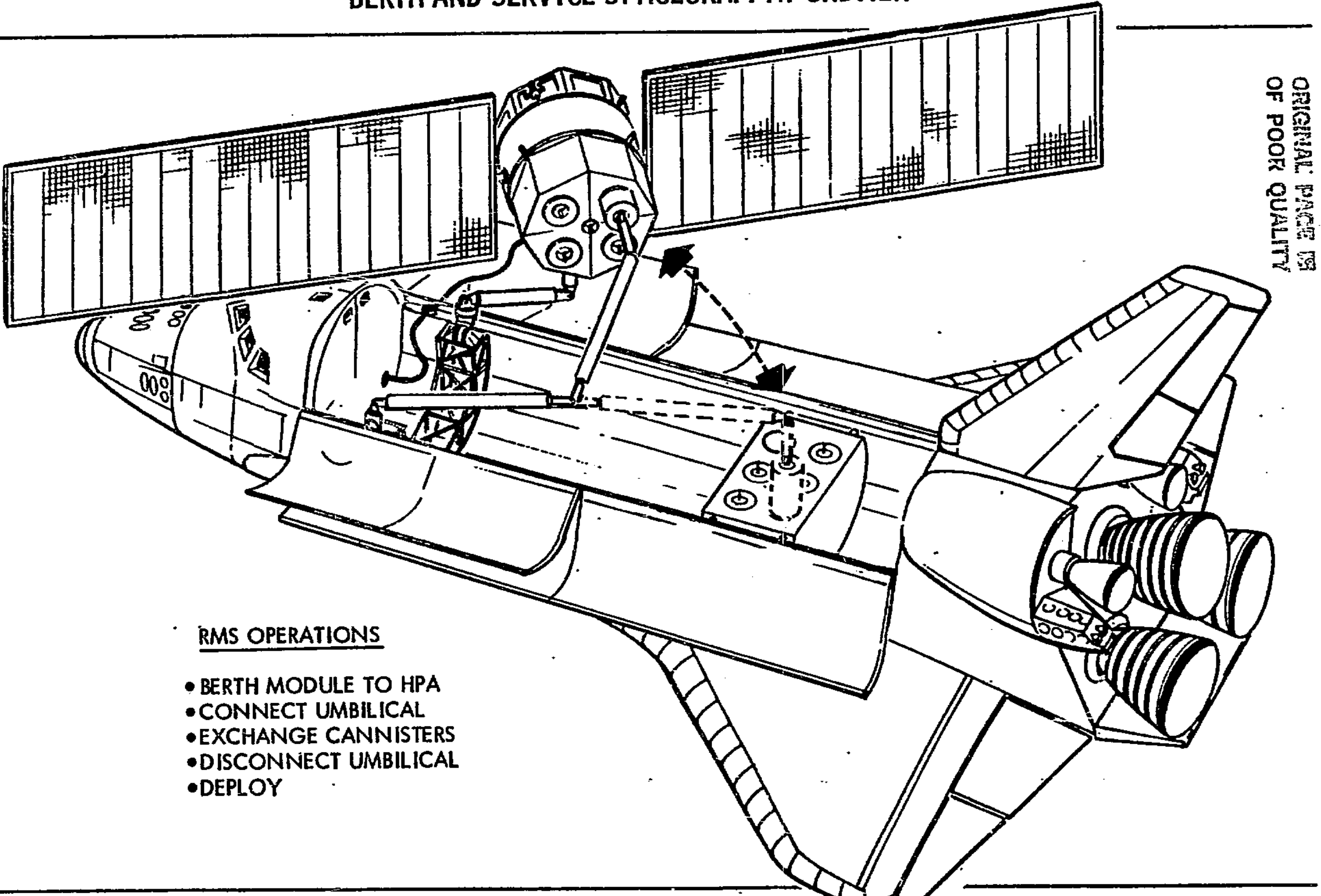
SPACE PROCESSING FACILITY
DEPLOY AND RETRIEVE SPACECRAFT BY ORBITER



- REMOVE MODULE FROM HPA WITH RMS, CLEAR ORBITER AND RELEASE
- RECAPTURE MODULE WITH RMS

SPACE PROCESSING FACILITY
BERTH AND SERVICE SPACECRAFT AT ORBITER



RMS OPERATIONS

- BERTH MODULE TO HPA
- CONNECT UMBILICAL
- EXCHANGE CANNISTERS
- DISCONNECT UMBILICAL
- DEPLOY

OTV GROUND SERVICING IMPLICATIONS

SUMMARY OF REQUIRED SERVICE PROVISIONS & EQUIPMENT

OTV	GSE	ORBITER

• CRANE INTERFACE
• TRANSPORT DEVICE INTERFACE
• SERVICE FIXTURE INTERFACE
• PIDA INTERFACE
• HPA INTERFACE
• GRAPPLE FIXTURES
• VERTICAL PROCESSING
  • FACILITY INTERFACE
• ORBITER INTERFACE
  • STRUCTURAL
  • FLUID
	• <u>ORBITER PROCESSING FACILITY</u>
	  • CRANE
	  • OTV TRANSPORT DEVICE
	• <u>OTV PROCESSING FACILITY</u>
	  • OTV SERVICE FIXTURE WITH SERVICE CORRECTIONS
	  • FUNCTIONAL TEST STATION
	  • LRU STORAGE
	  • MANUAL TOOLS FOR ASSEMBLY/ DISASSEMBLY
	  • CRANE
	• <u>VERTICAL PROCESSING FACILITY</u>
	  • CRANE
	  • VERTICAL PAYLOAD HANDLING DEVICE
	  • P/L BAY INTERFACE MOCKUP
	• <u>ROTATING SERVICE STRUCTURE</u>
	  • CRANE
	  • FLUID TANKAGE & UMBILICALS
	  • PAYLOAD GROUND HANDLING MECHANISM
		• STD ORBITER PLUS
		• PIDA
		• HPA
		• OTV FLUIDS INTERFACE
		• OTV ELECT INTERFACE

OTV-SOC SERVICING IMPLICATIONS

SUMMARY OF REQUIRED SERVICE PROVISIONS & EQUIPMENT

OTV	SOC
• REMOTE SAFING SYSTEM	• OTV CONTROL & MONITOR STATION
• COMMUNICATION & DATA LINK TO SOC & GROUND OCC	• COMMUNICATION & DATA LINKS TO OTV & ITS GROUND OCC
• NON-PROPULSIVE VENT SYSTEM	• ACTIVE DOCKING PORT ON FSF WITH ALIGNMENT MONITORING SYSTEM
• DOCKING PORT WITH ALIGNMENT TARGET	• EXTENDABLE NON-PROPULSIVE BOOM
• OTV-SOC SYSTEM INTERFACES (3-FLUID & 1-ELECT). WITH DUAL QUICK DISCONNECTS	• MOBILE MANIPULATORS (2) WITH STD END EFFECTOR & SPEE
• OTV-SOC STRUCTURAL INTERFACES (2 PIDA DEVICES)	• CCTV CAMERA ON MOBILE MANIPULATORS
• OTV-SOC MANIPULATOR INTERFACES (2 GRAPPLE FIXTURES)	• OPEN CHERRY PICKER & MMU
• ACCESSIBLE COMPONENT DESIGN	• RETRACTABLE UMBILICALS -- 3 FLUID & 1 ELECT
	• LRU STORAGE & RETRIEVAL SYSTEM

COMMSAT - ORBITER SERVICING IMPLICATIONS

SUMMARY OF REQUIRED SERVICE PROVISIONS AND EQUIPMENT

COMMSAT	ORBITER
• PIDA HEAD • GRAPPLE FIXTURE • HPA INTERFACE • COMMSAT-ORBITER SYSTEM CHECKOUT INTERFACE • APPENDAGES WITH REMOTE RELEASE, DEPLOY & LATCH SYSTEM • MANUAL OVERRIDE PROVISIONS FOR ALL MECHANISMS • SAFING SYSTEM • COMMSAT - OTV STRUCTURAL & FUNCTIONAL INTERFACES • ACCESSIBLE COMPONENT DESIGN • COMMUNICATION & DATA LINKS WITH ORBITER & GROUND OCC	• PIDA • HPA • RETACTABLE UMBILICAL SYSTEM • OTV COMPATIBLE WITH COMMSAT • OPEN CHERRY PICKER & MMU • COMMSAT CONTROL & MONITER STATION • COMMUNICATION & DATA LINKS WITH COMMSAT & ITS GROUND OCC • SYSTEM CONTINUITY ORBITER - OTV-COMMSAT

COMSAT-SOC SERVICING IMPLICATIONS

SUMMARY OF REQUIRED SERVICE PROVISIONS & EQUIPMENT

COMMSAT	SOC	ORBITER
•PIDA HEAD •GRAPPLE FIXTURE •BERTHING PORT WITH ALIGNMENT TARGET •COMMSAT-SOC SYSTEM C/O INTERFACE •APPENDAGES WITH REMOTE RELEASE, DEPLOY, & LATCH SYS •SAFING SYSTEM •COMMSAT-OTV STRUCTURAL & FUNCTIONAL INTERFACES •ACCESSIBLE COMPONENT DESIGN •COMMUNICATION & DATA LINKS WITH SOC & GROUND OCC •MANUAL OVERRIDE PROVISIONS FOR ALL MECHANISMS	•MANIPULATOR WITH STD END EFFECTOR •CCTV CAMERA ON MANIPULATOR •ACTIVE BERTHING PORT WITH ALIGNMENT MONITORING SYSTEM •RETRACTIBLE UMBILICAL SYSTEM •OTV COMPATIBLE WITH COMMSAT •SYSTEM CONTINUITY SOC-OTV-COMMSAT •OPEN CHERRY PICKER & MMU •COMMSAT CONTROL & MONITER STATION •COMMUNICATION & DATA LINK WITH COMMSAT & ITS OCC	STD ORBITER PLUS •PIDA

SPF -- ORBITER SERVICING IMPLICATIONS

SUMMARY OF REQUIRED SERVICE PROVISIONS & EQUIPMENT

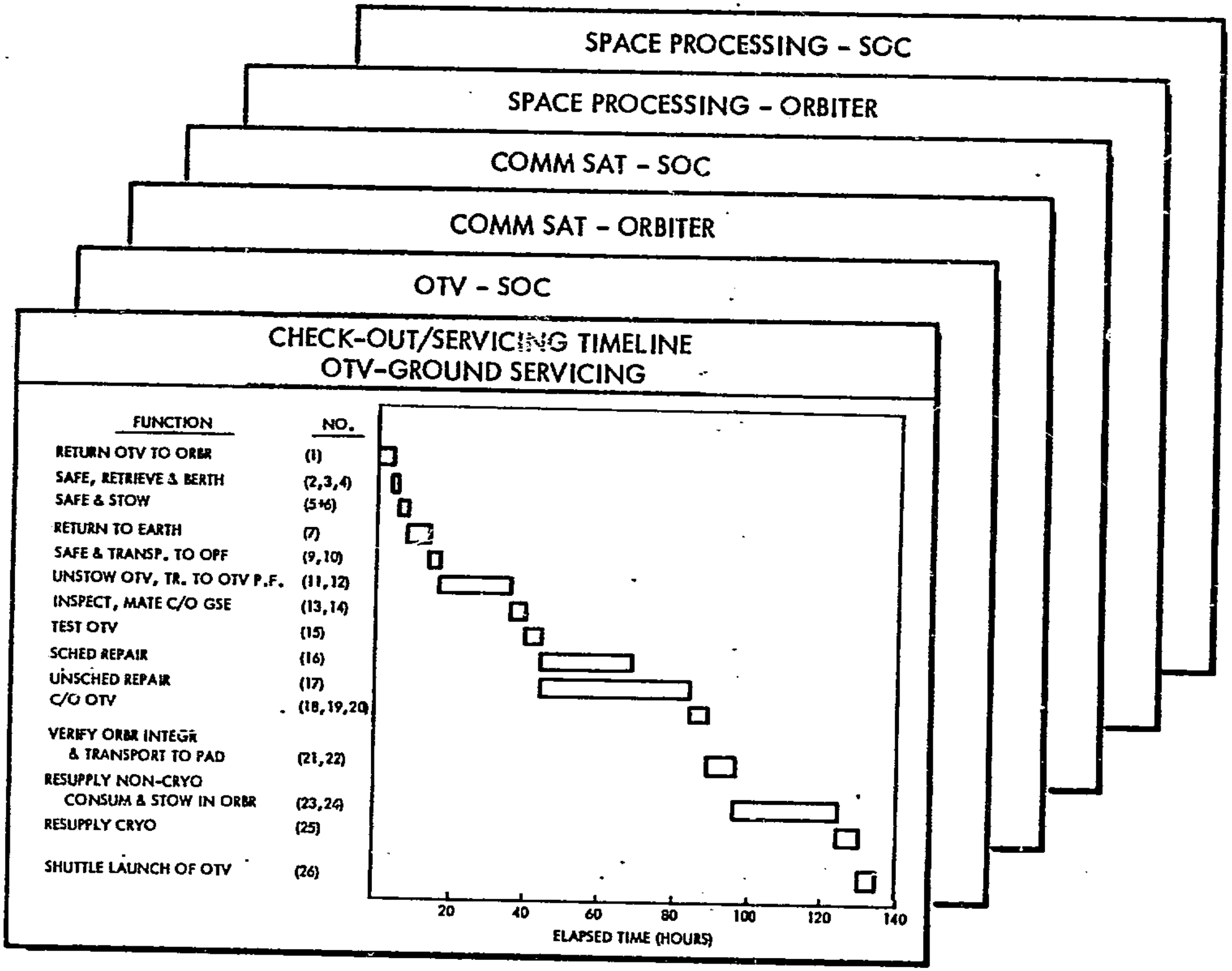
SPF	ORBITER
• GRAPPLE FIXTURE • PIDA HEAD FITTINGS • SPF-ORBITER SYSTEM INTERFACE • MODULE LATCHING & RELEASE MECHANISM • EXPERIMENT CANNISTER LATCHING & RELEASE MECHANISM • REPLACEABLE MODULE & CANNISTER DESIGN • COMMUNICATION & DATA LINK WITH ORBITER & GROUND OCC	• STANDARD ORBITER PLUS • SCUFF PLATES • HPA • SPF-ORBITER UMBILICAL • SPEE • MODULE & CANNISTER STORAGE & RETRIEVAL SYSTEM • MMU • COMMUNICATION & DATA LINK WITH SPF & ITS GROUND OCC

SPF-SOC SERVICING IMPLICATIONS

SUMMARY OF REQUIRED SERVICE PROVISIONS & EQUIPMENT

SPF	SOC	ORBITER
• GRAPPLE FIXTURE	• SPF CONTROL & MONITOR STATION	• STD ORBITER PLUS
• PIDA HEAD FITTINGS	• COMMUNICATION & DATA LINKS WITH SPF & ITS GROUND OCC	• SCUFF PLATES
• SPF-SOC SYST INTERFACE	• MOBILE MANIPULATOR WITH STD END EFFECTOR & SPEE	• HPA
• MODULE LATCHING & RELEASE MECHANISM	• CCTV CAMERA ON MOBILE MANIPULATOR	• MODULE & CANNISTER STORAGE
• EXPERIMENT CANNISTER LATCHING & RELEASE MECHANISM	• OPEN CHERRY PICKER & MMU	
• REPLACEABLE MODULE & CANNISTER DESIGN	• RETRACTABLE UMBILICALS WITH REFUELING PROVISIONS	
• COMMUNICATION & DATA LINK WITH SOC & GROUND OCC	• MODULE & CANNISTER STORAGE & RETRIEVAL SYSTEM	

CHECK-OUT SERVICING MANHOURS



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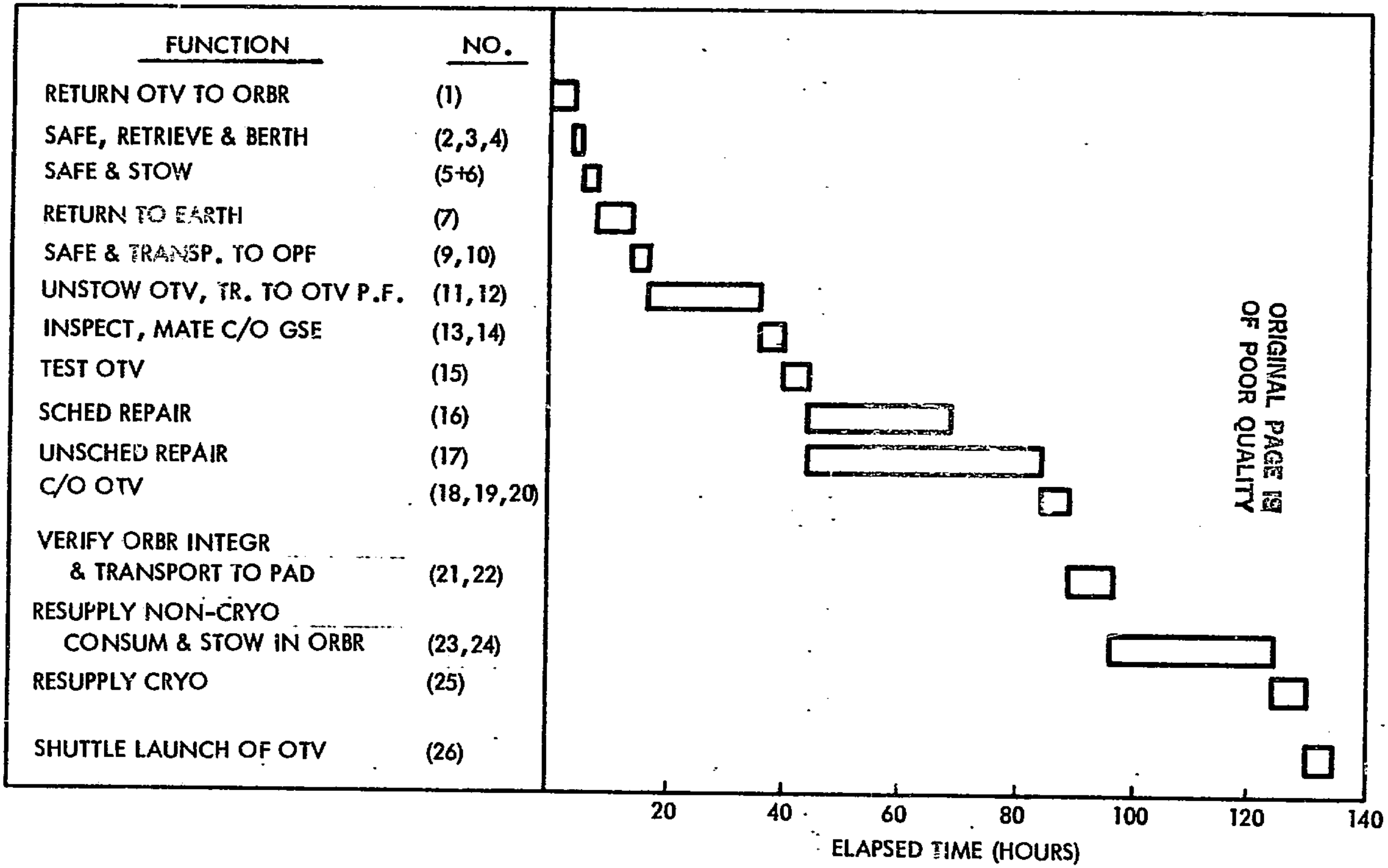
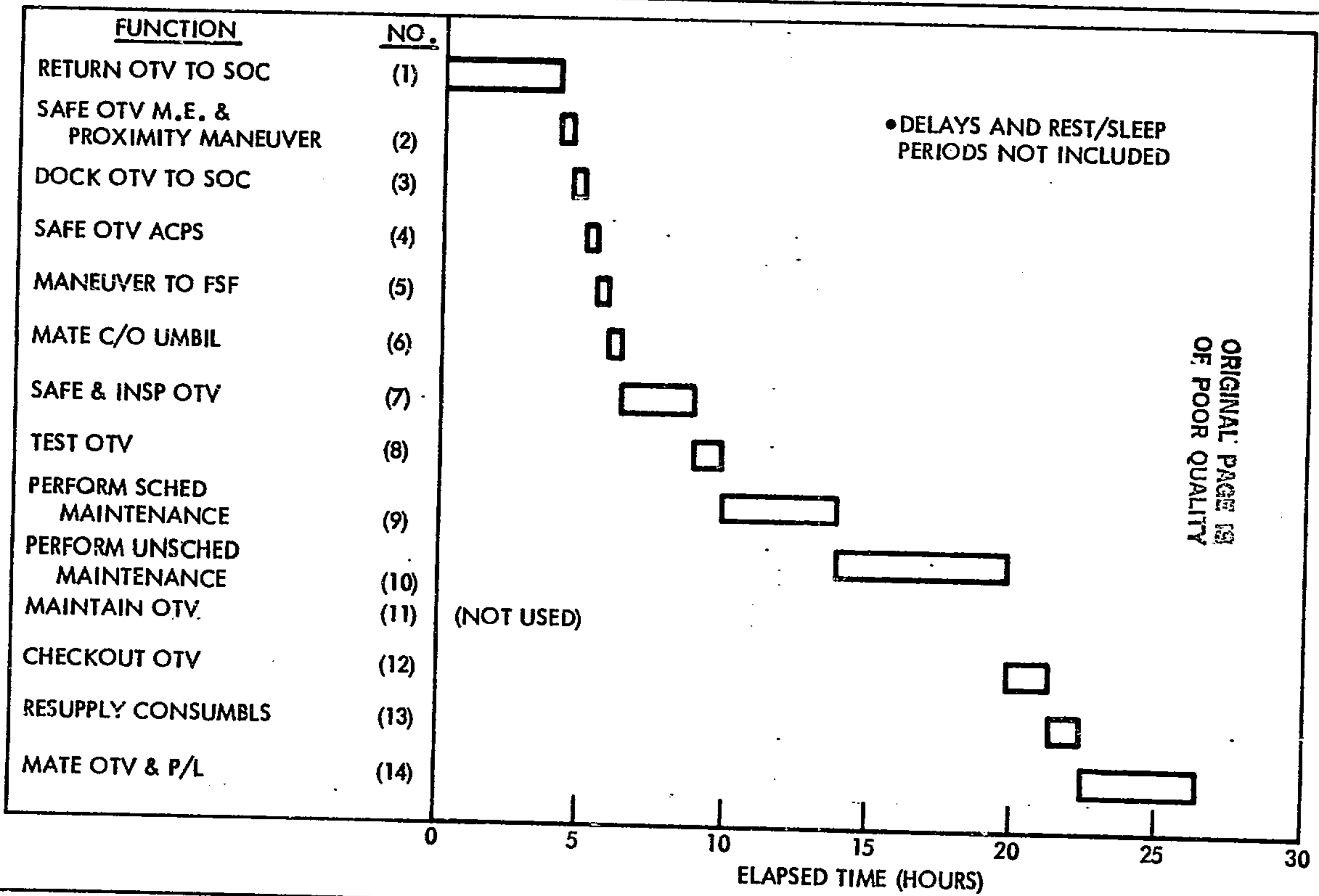
CHECKOUT/SERVICING TIMELINE
OTV -- GROUND SERVICING

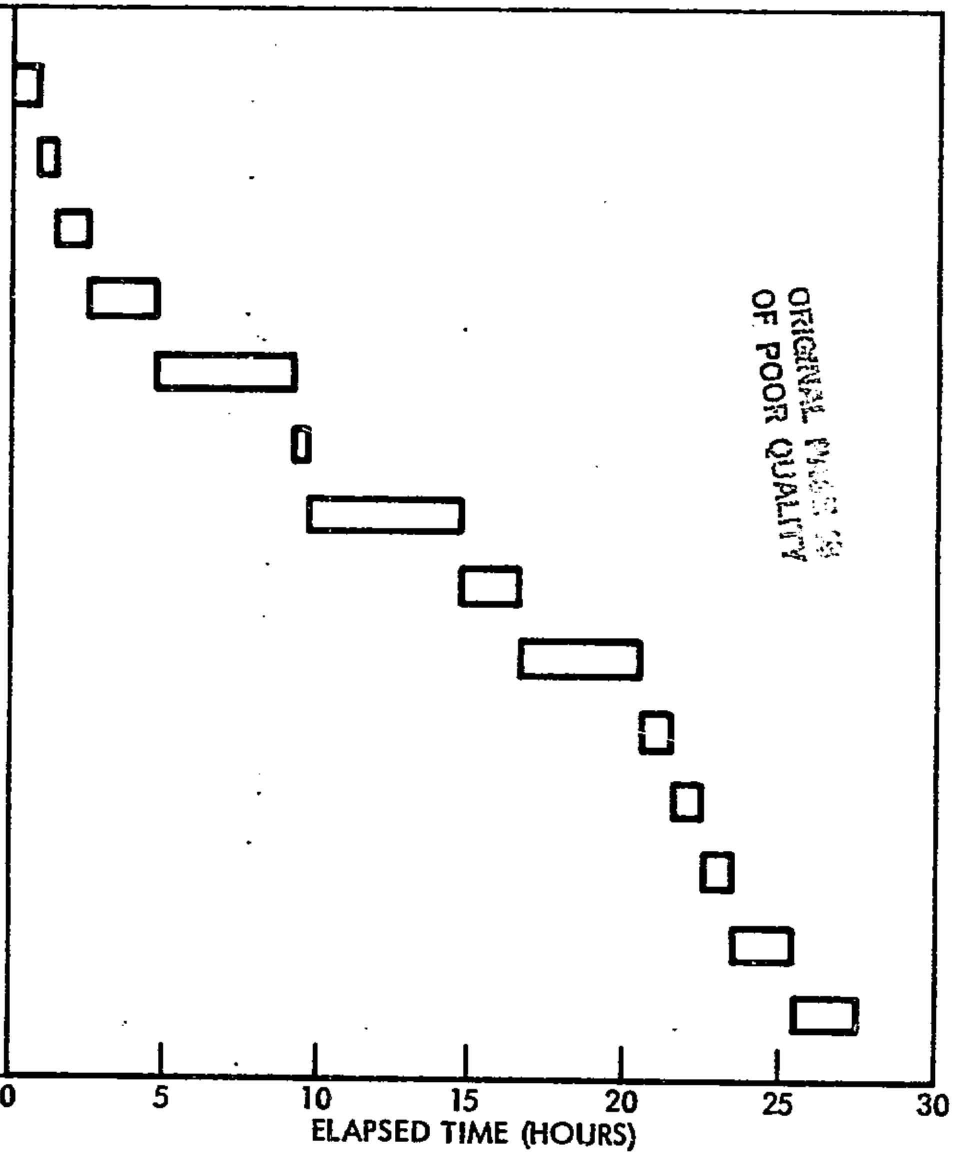


CHECKOUT/SERVICING TIMELINE
OTV TURNAROUND AT SOC
(INCL P/L MATE)



SPACE PROCESSING FACILITY
ORBITER TURNAROUND OPERATIONS -- TIMELINE

FUNCTION	NO.
SAFE & SHUTDOWN SPF	(8)
ACQUIRE SPF – RMS	(9)
BERTH SPF TO ORBITER	(10,11)
SAFE & INSPECT SPF	(12,13)
UNLOAD & STOW CANNISTERS	(14,15)
TEST SPF	(16)
UNSCHED MAINT & C/O	(17,17.1)
SCHED MAINT	(18)
LOAD MATERIALS CANNISTERS	(19)
CHECKOUT CANNISTER CONTROLS	(20)
SERVICE FUELS.	(21)
READY SPF – SEPARATION	(22)
SEPARATE SPF	(23,24)
MOVE ORBITER FROM SPF	(25,25.1)



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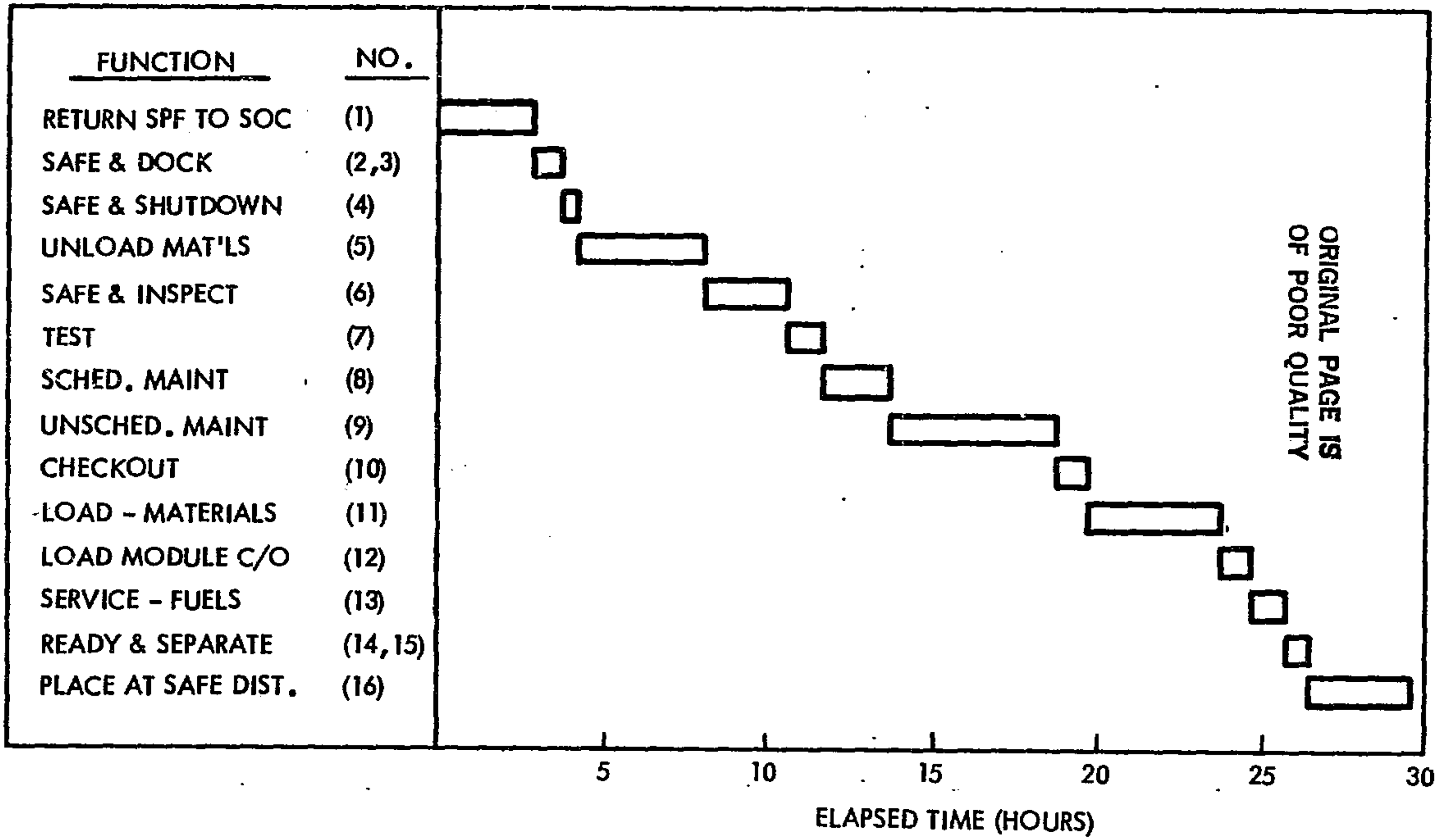
SPACE PROCESSING FACILITY
TURNAROUND OPERATIONS AT SOC



CHECK-OUT/SERVICING MANHOURS SUMMARY

LOCATION	ELAPSED TIME	MAN-HOURS	NO. CREW	
			RANGE	AVG
OTV - GROUND	134.0	576.0	3 - 6	4.3
OTV - SOC	26.3	99.7	3 - 5	3.8
COMM SAT - ORBITER	50.8	164.8	2 - 4	2.4
COMM SAT - SOC	61.0	199.6	2 - 5	2.6
SPACE PROCESSING - ORBITER	27.5	106.0	2 - 4	3.5
SPACE PROCESSING - SOC	29.6	103.4	3 - 4	3.5

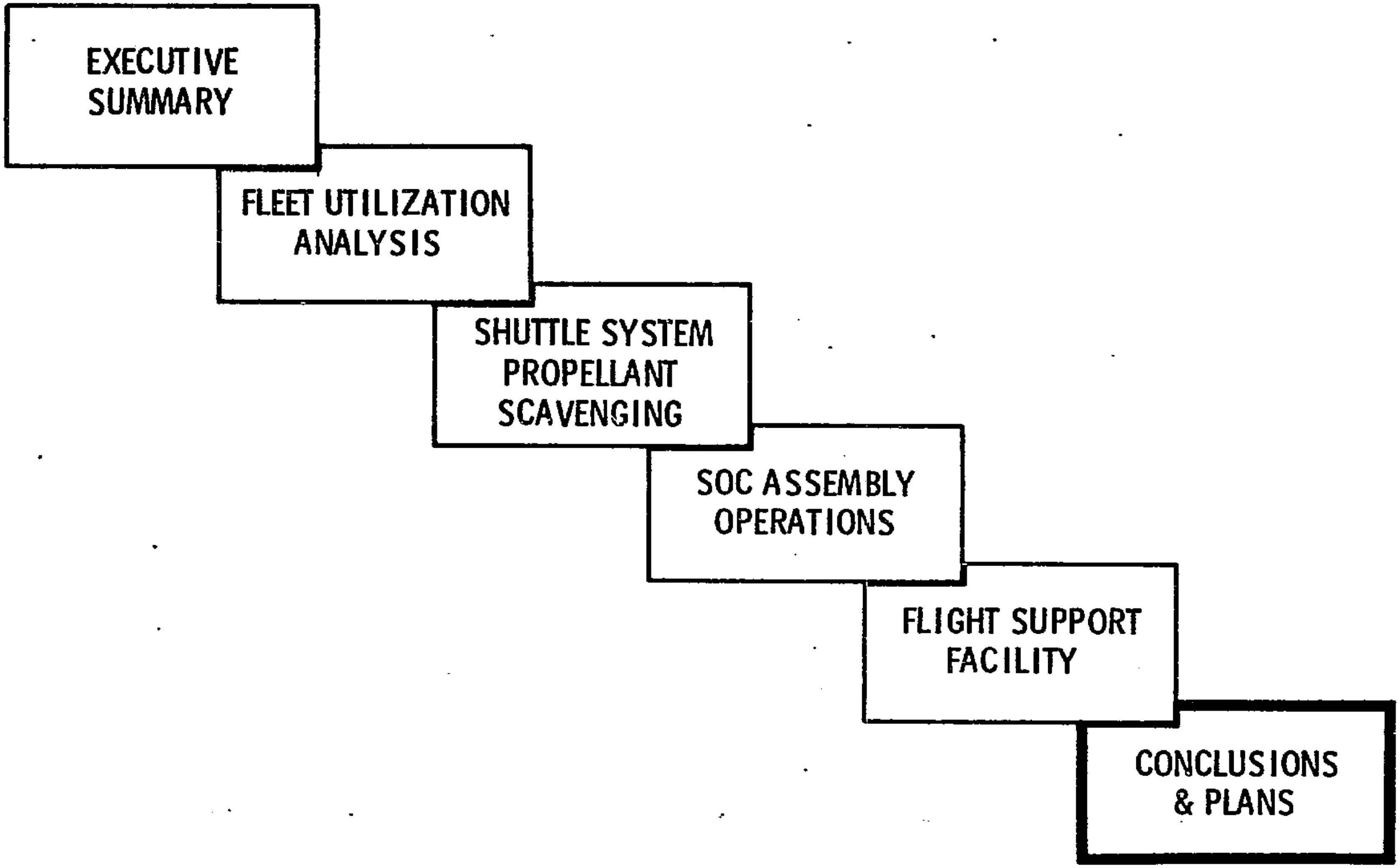
SUMMARY

COMPLETED TASKS

- GENERATED SERVICING SCENARIOS FOR 3 REF S/C (6 SERVICING CONDITIONS)
- ANALYZED ALL SERVICING SCENARIOS & DETERMINED IMPLICATIONS
- ESTIMATED SERVICING TIMELINES FOR 4 OF THE 6 CONDITIONS

TASKS TO BE COMPLETED

- ESTIMATE TIMELINES FOR COMMSAT SERVICING AT ORBITER & SOC
- PREPARE PRELIMINARY DESIGN LAYOUT OF SOC FSF & INTEGRATING RESULTS OF SERVICING SCENARIO ANALYSIS
- GENERATE & COMPARE SERVICING COST DATA


EXECUTIVE SUMMARY
FLEET UTILIZATION ANALYSIS
SHUTTLE SYSTEM PROPELLANT SCAVENGING
SOC ASSEMBLY OPERATIONS
FLIGHT SUPPORT FACILITY
CONCLUSIONS & PLANS

CONCLUSIONS AND PLANS

- FLEET UTILIZATION ANALYSIS HAS BEEN STARTED...
  - IMPORTANT RESULTS ARE EXPECTED
- SOC ASSEMBLY ANALYSIS UNDERWAY...
  - COMPUTER INTERACTIVE GRAPHICS WILL GIVE HIGH CONFIDENCE TO CLEARANCE GEOMETRIES
- ET PROPELLANT SCAVENGING PROVEN FEASIBLE...
  - AMPLE TRANSFER TIME
  - ET IMPACT SATISFIED
  - NO SIGNIFICANT STS PAYLOAD IMPACT
  - ACCEPTABLE SAFETY STANDARDS CAN BE MET
  - WIDE RANGE OF APPLICATION SCENARIOS IS POSSIBLE
- FLIGHT SUPPORT FACILITY ANALYSIS WELL UNDERWAY...
  - SERVICING IMPLICATIONS IDENTIFIED
  - SERVICING TIMELINES AND COST DATA ARE BEING GENERATED
  - KEY INSIGHTS INTO COST EFFECTIVENESS OF VARIOUS SERVICING SCENARIOS WILL BE GAINED